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INDOOR ENVIRONMENT-RELATED HOARSENESS AMONG FINNISH HEALTH CARE PROFESSIONALS

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To My Loved Ones

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ABSTRACT

A well working voice is an essential tool for healthcare professionals to achieve high levels of patient satisfaction and safety, yet the prevalence of hoarseness, influenced by factors like noise, acoustics, and pollutants, remains under-researched. The overall purpose of this study was to investigate the prevalence and risk factors associated with hoarseness among healthcare professionals, with a particular focus on issues of indoor environmental quality (IEQ). This thesis consists of two elements, a nationwide survey based on random sampling (Studies I and II) and a clinical section (Studies III and IV), which also included a follow-up. In the first part of the study, the health data were collected with a questionnaire answered by Finnish health care professionals (N=15,553) and in the clinical part, all the participating buildings (N=33) were inspected by qualified construction prior to being classified as "exposed" or "reference" buildings. Additionally, for the Study IV, skin prick tests were performed and/or blood samples were taken from all volunteers (N=496).

Results revealed that 30% of professionals reported frequent hoarseness, with variations evident across occupational subgroups and between different buildings. Midwives experienced the highest prevalence, while laboratory nurses had the least. A significant correlation was observed between perceived IEQ issues and hoarseness, especially in exposed buildings. Over a decade, hoarseness did not increase in environments with good IEQ but was six times higher in exposed buildings.

Major risk factors for hoarseness included unresolved IEQ problems, age, smoking, allergies, and asthma. Contrary to popular belief, the results of this study suggest that hoarseness largely results from larynx irritation rather than allergic reactions. Interestingly, professions with higher chemical exposure, like dental nurses, did not show increased hoarseness. Remedying exposed buildings decreased hoarseness prevalence, but not to levels in reference buildings. Given the high prevalence and the potential health and productivity impact, the findings underscore the urgent need for IEQ improvements, particularly in ventilation and moisture damage repair, in order to ensure safer and healthier working conditions for healthcare professionals.

KEYWORDS: Hoarseness; occupational health; healthcare professionals; environmental problem; indoor air quality

TURUN YLIOPISTO
Lääketieteellinen tiedekunta
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TIIVISTELMÄ

Hyvin toimiva ääni on yksi tärkeimmistä työkaluista, joita terveydenhuollon ammattilaiset tarvitsevat saavuttaakseen korkean potilastyytyväisyyden ja turvallisuuden. Siitä huolimatta käheyden yleisyyttä terveydenhuollon ammattilaisten keskuudessa ei ole paljoa tutkittu, vaikka heidän työympäristössään on monia altistavia tekijöitä, kuten taustamelu, huono akustiikka tai kemikaalit ja muut ilman epäpuhtaudet, jotka heikentävät äänen terveyttä ja suorituskykyä. Tämän tutkimuksen tarkoituksena oli selvittää terveydenhuollon ammattilaisten käheyden yleisyyttä ja sen riskitekijöitä, erityisesti sisäympäristön laatuun liittyviä tekijöitä. Tutkimus koostuu kahdesta osasta, valtakunnallisesta satunnaisotokseen perustuvasta tutkimuksesta (Tutkimukset I ja II) ja kliinisestä osasta (Tutkimukset III ja IV), johon sisältyi myös seuranta. Tutkimuksen ensimmäisessä osassa terveystiedot kerättiin kyselylomakkeella suomalaisilta terveydenhuollon ammattilaisilta (N=15 553) ja tutkimuksen kliinisessä perehtyneet rakennusinsinöörit tarkastivat kaikki rakennukset (N=33) ennen kuin ulkopuoliset asiantuntijat luokittelivat ne "vaurio-" tai "vertailurakennuksiksi". Lisäksi osatyötä n:o IV varten tehtiin ihopistokokeet ja/tai otettiin verinäytteet kaikilta vapaaehtoisilta (N=496).

Tulosten mukaan, jopa 30 prosentilla oli toistuvaa käheyttä, ja erot olivat merkittäviä eri ammattialaryhmien ja eri rakennusten välillä; kätilöillä käheys oli yleisintä ja vähiten sitä esiintyi laboratoriohoitajilla. Merkittävästi enemmän käheyttä esiintyi, ns. vauriorakennuksissa. Yli 10 vuotta kestäneen seurannan aikana käheyden esiintyvyys vertailurakennuksissa on pysynyt alhaisena, kun samanaikaisesti vauriorakennuksissa esiintyvyys oli jopa kuusinkertainen.

Merkittävimpiä riskitekijöitä olivat sisäympäristön ongelmat ikä, tupakointi, allergiat, ja astma. Yleisestä käsityksestä poiketen, tämän tutkimuksen tulokset viittaavat siihen, että käheys johtuu suurelta osin kurkunpään ärsytyksestä eikä allergisista reaktioista. Mielenkiintoista on, että ammateissa, joissa on suurempi kemikaalialtistus, kuten hammashoitajilla, ei käheyttä esiintynyt merkittävästi enempää. Vauriorakennusten korjaaminen vähensi käheyden esiintyvyyttä, mutta vertailurakennusten tasolle ei päästy. Huomioiden korkea käheyden esiintyvyys sekä siihen liittyvät mahdolliset terveys- ja tuottavuusvaikutukset, havainnot korostavat tarvetta, erityisesti ilmanvaihto- ja kosteusvaurioiden korjaamisessa, jotta terveydenhuollon ammattilaisten työolot olisivat turvallisemmat ja terveellisemmät.

AVAINSANAT: Käheys; työterveys; terveydenhuollon ammattilaiset; ympäristöongelma; sisäilman laatu

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Abbreviations

CO	Carbon monoxide
FINAS	Finnish Accreditation Service
H_2S	Hydrogen sulfide
IgE	Immunoglobulin E
IgG	Immunoglobulin G
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
PHC	Primary health care center
RH	Relative humidity
Tehy	Union of Health and Social Care Professionals
SPSS	Statistical Package for Social Sciences
SPT	Skin prick test
SuPer	Suomen lähi- ja perushoitajaliitto (The Finnish Union of Practical Nurses)
VOC	Volatile organic compound

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Vilén L, Putus T. Hoarseness among nurses. *Journal of Voice*, 2023, 37(5): 798.e15-798.e18. https://doi.org/10.1016/j.jvoice.2021.03.030

II Vilén L, Atosuo J, Putus T. Prevalence of hoarseness in primary health care and hospitals – associations with different work tasks and environmental factors among nurses. *Journal of Voice*, 2022; https://doi.org/10.1016/j.jvoice.2022.02.024. Online ahead of print.

III Vilén L, Atosuo J, Putus T. The prevalence of hoarseness among health care professionals: time trends and effect of remediation in working conditions in 2007-2018. *International Archives of Occupational and Environmental Health,* 2022; https://doi.org/10.1007/s00420-022-01934-9. Online ahead of print.

IV Vilén L, Atosuo J, Putus T. The association of voice problems with exposure to indoor air contaminants in health care centres – the effect of remediation on symptom prevalence: a follow-up study. *Indoor and Built Environment*, 2023; https://doi.org/10.1177/1420326X231197184. Online ahead of print.

1 Introduction

For most professions, the most important means of communication is speech. A well-functioning voice is also a critical tool for healthcare professionals, it can even be stated that it is almost a prerequisite for achieving high treatment satisfaction and safety (Johnsson et al., 2018). In health care, the requirements for the voice are good durability and audibility, and to meet these requirements the vocal system must be healthy; a voice problem significantly decreases the speech intelligibility (Porcaro et al., 2020). However, in the health care environment there may be factors like chemicals and other air pollutants which may impair the health and performance of the vocal system, in addition to better-recognized risk factors such as background noise or poor acoustics.

According to one estimation, in industrialized countries, 50% of the entire workforce works in buildings, which have inadequate ventilation, temperature changes, humidity, chemical or/and biological contaminants (Abdel Hamid et al., 2013). Therefore, the indoor environmental quality (IEQ) has become a matter of growing concern in many countries (Al Horr et al., 2016; Szczurek et al., 2018). The IEQ problems, caused by moisture damage and inadequate ventilation have also been a matter of concern in Finnish hospitals and health care units since mid-1990s (Hellgren, 2006; Reijula, 2005). Harmful environmental exposures are etiologically related to a significant part of respiratory diseases (Cincinelli & Martellini, 2017; Lanthier-Veilleux et al., 2016). The most common health effects associated with indoor air problems are asthma, upper respiratory tract infections and other respiratory symptoms such as wheezing, coughs, bronchitis, and rhinitis, all of which may also affect voice quality (Crook & Burton, 2010; Fung & Hughson, 2003; Heseltine & Rosen, 2009; House & Fisher, 2017; Hurraß et al., 2017; Mihinova & Pieckova, 2012; Osborne et al., 2015; Patovirta, 2005; Reiter et al., 2015; Wiesmüller et al., 2017).

Despite this being a general problem, the research on voice problems has mainly focused on professional speakers, like teachers with the result that health care professionals have not received much attention (Byeon, 2019; Chen et al., 2010; Morawska & Niebudek-Bogusz, 2017; Putus et al., 2021; Roy et al., 2005; Vertanen-Greis et al., 2018), even though almost all known risk factors for hoarseness are present in their everyday work. Therefore, this study focuses on hoarseness as a single symptom among health care professionals by investigating the prevalence, possible risk factors as well as how the prevalence has changed over the past decade.

2 Review of the Literature

2.1 Indoor environmental quality (IEQ)

The quality of the indoor environment is a relative measure of the comfort of people exposed to indoor conditions, which is affected by factors like indoor air quality (IAQ), thermal environment, acoustic (soundscape) and visual (lighting, daylight, view) environment. (Larsen et al., 2020; Mallawaarachchi et al., 2016; Piasecki et al., 2017). It has been shown to increase the comfort, the health, and the well-being of building users. Moreover, its economic consequences are reflected in lower health care expenditures and increased productivity (Clark et al., 2020; Mallawaarachchi et al., 2016).

In this review, the concept of a thermal environment is combined with the concept of IAQ and are treated as one, this is because ventilation and heating are often adjusted together. The acoustic comfort represents an acoustic environment suitable to those working/living in a building while maintaining the original purpose of the building and shielding the occupants from noise (Mujan et al., 2019). However, hospitals and health care buildings in general are designed with particular consideration for their special requirements in the space and it is impossible for a layman to evaluate e.g. the construction engineering solutions. Therefore, the focus here is only on perceived environmental noise. Although the visual environment is one component of the IEQ, its potential influence on hoarseness was not considered in this study and is therefore not discussed further in this review.

2.1.1 Indoor air quality (IAQ)

Clean air is a basic requirement of life influencing the well-being of the people. Nowadays when we spend most of our time indoors, the quality of indoor air has become a matter of growing concern in many countries (Al Horr et al., 2016; Chang & Gershwin, 2004; Li et al., 2007; Pei et al., 2022; Szczurek et al., 2018).

The concept of indoor air quality encompasses a wide variety of factors including the temperature, humidity, the presence of contaminants, and the quality of outdoor air brought inside (Śmiełowska et al., 2017; Stipe, 2015) and therefore it is affected by many factors, e.g. meteorological conditions, the building characteristics, contaminants, maintenance and operation of heat, ventilation and air conditioning system, as well as occupancy; it is a result of the interplay between all these factors (Ibrahim et al., 2022; Mentese & Tasdibi, 2016) (**Table 1**). However, the main key factor affecting indoor air quality is how the ventilation-system, more specifically the heating, ventilation, and air-conditioning is organized (Seppänen & Fisk, 2002). A well-working ventilation-system removes indoor-generated contaminants from inside the building or dilutes their concentration to acceptable levels and commonly also controls the temperature and humidity (Engvall et al., 2005; Seppänen & Fisk, 2004).

Table 1. Factors influencing indoor air quality.

FACTOR INFLUENCING INDOOR AIR QUALITY	E.G.
Meteorological conditions/climate	floods, heavy rains, heat, humidity, seasons
Building design/characteristics	building envelope designs, construction and finishing materials, furnishing
Occupants' characteristics	occupant activities, medical activities
Heating, ventilation and air conditioning systems (HVAC)	adequacy and maintenance
Maintenance	maintenance of the building, water and sewer lines, hygiene maintenance

In evaluating the perceived indoor air quality (IAQ), sensory effects are important parameters even though some air pollutants, such as radon or CO cannot be sensed (Seppänen & Fisk, 2004). For odors and sensory irritating air pollutants the chemical and physical assessments methods are often insensitive and therefore quite often sensory tests are the only tool for the evaluation of the perceived indoor air quality (Berglund et al., 1999). For instance, moldy or cellar-like odors may reveal the invisible mold contamination hidden behind the ceilings, wallpaper, walls, and floors, even when the water leaks or condensation are not apparent (Osborne et al., 2015). Moreover, in the study of homes with a moldy odor, Reponen et al. (2010) investigated the associations between visually observed mold damage and mold odors and several quantitatively assessed exposure variables. Their study found that homes with moldy odors had the highest concentrations of the measured microbial contaminants. The same applies to sewage gases, the smell of a sewer, recognizable by the smell of a "rotten egg" can reveal sewer leaks. The easily recognizable smell of sewer comes from hydrogen sulfide (H_2S), which is known to be toxic at relatively low concentrations (Knight & Presnell, 2005). Therefore, in studies of large populations, the use of a questionnaire survey as a source of information about indoor air quality is justified (Järvi et al., 2018; Lewkowska et al., 2017). A simple summary is that good indoor air has a neutral smell, that both the humidity and temperature are comfortable, and that is does not contain harmful impurities (Finnish Institute of Health and Welfare, 2022).

2.1.1.1 Indoor air quality in health care environment

In the health care environment, the personnel are in direct contact with various types of pollutants, which are often categorized based on the origin; biological - and chemical pollutants (Ghanizadeh & Godini, 2018). The pollutants in health care environment are predominantly considered to arise from the biological contaminants, such as bacteria, mold, and viruses (Cabo Verde et al., 2015; Ghanizadeh & Godini, 2018; Hope, 2013; Israeli & Pardo, 2011; Soleimani et al., 2016; Srikanth et al., 2008). In addition to biological contaminants, chemical hazards also play a notable role in indoor air problems in health care environments. Health care workers are exposed to a varying range of chemical compounds emitted from disinfectants and sterilizing products, anesthetic gases, and laboratory- or pharmaceutical products (Bessonneau et al., 2013; Delclos et al., 2007). In addition, Bessonneau et al. (2013) have assessed over 40 different volatile organic compounds (VOCs) in the indoor air in different locations in hospitals. However, although the concentrations of all measured compounds were largely below occupational exposure limits, healthcare workers were exposed to a complex mixture of VOCs. In addition to the work-related VOCs, healthcare workers can also be affected by VOCs emitted from building and decoration materials (Bessonneau et al., 2013).

Hospital buildings are usually associated with moisture problems (Othman et al., 2015) the causes of which are often complex and diverse. Water is used extensively in healthcare; it is needed e.g. in equipment maintenance, cleaning, and patient hygiene. In addition to the everyday use of water, moisture may also occur in building materials as a result of liquid flow from leaks, condensation, capillary movement, air movement or vapor diffusion (Nevalainen & Seuri, 2005). One consequence of the moisture is that as soon as the RH achieves a minimum limit of approximately 65%, the microbial growth starts in the substrate (Seguel, 2017). Furthermore, in addition to microbial growth, the moisture may also lead to emission of chemicals from damaged building materials and furnishings (Bernstein et al., 2008; Heseltine & Rosen, 2009).

The Finnish hospitals and health care units have suffered from indoor air problems caused by moisture damage and inadequate ventilation from at least since mid-1990s. One explanation for this is that most of the buildings are relatively old and their ventilation technology and sewer systems are outworn, and they do not meet current demands. Moreover, the fact that the water intrusion is often left unrepaired for long periods and there is insufficient maintenance is worsening the problem. (Hellgren & Reijula, 2011). Since many healthcare facilities are often looking for ways to save money, such maintenance problems may be quite common (Riley et al., 2004).

In 2005, The Ministry of Social Affairs and Health carried out a survey, where ten central hospitals were studied more thoroughly to evaluate the influence of building condition, construction faults, ventilation and indoor air quality on workers' and patients' health. The survey showed that there was immediate need for repair due to moisture damage in 15% of the hospital facilities (Reijula, 2005). In addition, major repairs of the ventilation systems were needed in 40% and minor repairs in 20% of the hospitals (Hellgren et al., 2011; Hellgren & Reijula, 2011).

Temperature variations are a common problem when the ventilation system is not able to circulate the air properly. The light warm air rises and the heavier cooler air sinks causing the phenomenon where the temperature near the ceiling can be several degrees warmer than at floor level (Sharkawy & Noweir, 2014). This is not only uncomfortable for the users of the space, but it can be considered also a risk factor for indoor air problems, because when the air condenses on a cooler surface, it creates moisture, which can promote the growth of microbes. (Osborne et al., 2015). Additionally, ventilation that does not work properly may bring harmful contaminants or odors into indoor air and may also affect the air and moisture flow though the building's envelope, which may lead to moisture damage. Ventilation also changes the pressure differences over the structures of the building, and this may lead to the infiltration of pollutants from structures or adjacent spaces. (Seppänen & Fisk, 2004). Despite the wide variety of factors influencing the indoor air quality, moisture, and inadequate ventilation in collaboration with poor maintenance are considered to be the main reasons for indoor air problems (Crook & Burton, 2010; Othman et al., 2015; Pei et al., 2022; Singh et al., 2010; Szczurek et al., 2018).

2.1.2 Indoor environmental noise

The indoor environment is never quiet; noise can come from outside the building (e.g., traffic, airplanes, public) or from sources inside the building (conversations, various devices or machines, ventilation, etc.). What is considered to be "noise" depends upon the listener and the circumstances, thus it is a relative concept. Briefly, "noise is any unwanted and/or harmful sound." (Fink, 2019). Although noise is an integral part of modern society, it is also an important public health issue. In Finland, the law determines occupational noise exposure levels that are considered dangerous in terms of the risk of hearing loss (85/2006, 2006). A sound intensity of over 85 dB is considered to cause noise-induced hearing loss, although the sensitivity of each individual is different (Ding et al., 2019). However, noise has also been shown to have many negative health effects at lower levels, such as annoyance, sleep disorders, learning and concentration disorders, and cardiovascular effects (Hammer et al., 2014; Montes-González, Barrigón-Morillas, Gómez Escobar, et al., 2019; Singh & Davar, 2004)

2.1.2.1 Environmental noise in healthcare environment

Hospitals and other healthcare environments have multiple sources of noise, such as alarms, telephones, air conditioning systems, staff conversations, televisions, delivery carts, ventilators and other medical equipment, high intensity alarms to announce medical emergencies, staff-patient conversations, opening and closing doors, etc. In addition, some of the noise also comes from outside the buildings into the interior, such as traffic noise (cars, ambulances, helicopters). (Busch-Vishniac & Ryherd, 2019; Cunha & Silva, 2015; Joseph et al., 2020; Montes-González, Barrigón-Morillas, Escobar, et al., 2019). As summed up by Busch-Vishniac and Ryherd (2019, p. 17): “Hospital soundscapes do not currently project an aura of calm and restfulness that patients and staff would prefer. Instead, they are loud and chaotic, with lots of sound peaks from normal hospital operations and medical equipment.”

Multiple studies have shown that noise is increasing from year to year and emitted level of noise is higher than allowed by the WHO or Finnish law (Arifianto et al., 2018; Busch-Vishniac et al., 2005; Busch-Vishniac & Ryherd, 2019; Cunha & Silva, 2015; de Lima Andrade et al., 2021; 545/2015, 2015). Based on systematic review of the literature by de Lima Andrade et al. (2021), the average noise levels of indoor hospital environments vary from 37 to 88.6 dB in the daytime and are only slightly lower at night. As for comparison, the noise level of regular conversation is 50-70 dB and traffic noise around 70-85 dB (Kuuloliitto ry, 2023). Most of the noise in hospitals is in the frequency range of regular conversation (de Lima Andrade et al., 2021; Kuuloliitto ry, 2023), which makes oral communication difficult; it forces doctors and nurses to speak even louder to be heard which of course strains their voices (Zollinger & Brumm, 2011).

2.2 Hoarseness

Hoarseness is a symptom referring to the patient’s experience of altered voice quality, such as roughness, weakness or the voice may even disappear into a whisper. The symptom is easy to detect by listening and people recognize the change themselves (Born & Rameau, 2021; Karppinen, 2023; Perenyei et al., 2018). It is a very common symptom from which nearly one in three of the general adult population seeks for medical care at some point in their life (Cohen et al., 2012;

Pylypowich & Duff, 2016; Roy et al., 2005; Stachler et al., 2018). And because not everyone with hoarseness seek treatment, especially if the symptoms are temporary and/or related to an upper respiratory tract infection, the true proportion is most likely higher (Born & Rameau, 2021; Pylypowich & Duff, 2016). Hoarseness may occur in all ages and genders; however, the risk is higher among woman and among professions with heavy vocal loading (Lyberg-Åhlander et al., 2019; Neighbors & Song, 2023; Pylypowich & Duff, 2016; Vilkman, 2004; Williams, 2002). The higher prevalence found among women, might be due to the physiological differences between the genders. For instance, women's vocal folds are on average 60% shorter and about 20–30% thinner than men's. This difference in thickness is primary due the testosterone during the puberty which grows the muscle within the vocal folds. The smaller structures correlate with higher vibratory frequencies; women's vocal folds vibrate about two hundred times per second as they speak, while the corresponding rate among men is about one hundred times per second (Cohen et al., 2012; Hunter et al., 2011; Kleemola & Sala, 2013; Marchese et al., 2022; Schwartz et al., 2009; Stachler et al., 2018; Vilkman, 2004). However, although physiological and anatomical differences between the genders exist, the higher risk among women is currently based on a purely epidemiological point of view (Marchese et al., 2022).

Colloquially the terms hoarseness and dysphonia are often used as synonyms, however hoarseness is a symptom of which the medical diagnosis made by a clinician is dysphonia (Born & Rameau, 2021; Perenyei et al., 2018). The clinician's assessment of dysphonia includes e.g. qualitative evaluation of the patient's voice, objective aerodynamic and acoustic analysis, and instrumental research of vocal language (Born & Rameau, 2021). Based on the findings, dysphonia can be classified into two categories, organic and functional (Neighbors & Song, 2023). Functional dysphonia refers voice problems without any clear anatomical, neurological, or other organic findings (Behlau et al., 2015; Millar et al., 1999; Neighbors & Song, 2023). Organic dysphonia can result from any either structural (e.g. cyst or polyp) or neurological disorders (e.g. paralysis) affecting larynx, but hoarseness primarily results from vocal fold changes, either a vocal fold closure disorder or the vibrational properties of the mucous membrane; the symptom occurs if air leaks abnormally between the vocal folds (House & Fisher, 2017).

The causes of hoarseness may be a consequence of many different factors such as infection, inflammation or irritation, tumor, neuromuscular and a psychiatric (e.g. stress) or related systemic illness. Nevertheless, the most common causes are short-term vocal overuse and viral upper respiratory infections. In more than over half of the cases, laryngitis (acute or chronic) is the main reason for hoarseness. Other common causes are smoking, abundant voice overuse as well as various irritants, such as different environmental irritants, laryngopharyngeal reflux, allergies, or inhaled corticosteroids. Even though the possible etiology can range from benign to malignity, the proportion of malignity in cases of hoarseness is low, somewhere around 2-3%. (Pylypowich & Duff, 2016; Reiter et al., 2015). Although hoarseness is rarely a sign of a serious illness, it has been found to have a negative effect on people's ability to work and professional self-esteem. Moreover, many people suffer from social isolation, depression, anxiety, and other lifestyle changes because of the voice problem (Behlau et al., 2015; Stachler et al., 2018; Verdolini & Ramig, 2001).

2.2.1 Environmental risk factors for hoarseness

The primary risk factors for hoarseness include prolonged voice use and environmental factors, such as background noise and indoor air quality (Morawska & Niebudek-Bogusz, 2017; Rantala et al., 2012; Vilkman, 2004). The effect of background noise on the voice production has been recognized for over 100 years, it is called the Lombard effect; when the background noise rises, naturally the volume of the voice increases at the same pace, which in the long run, overloads the voice (Zollinger & Brumm, 2011). The concept of indoor air quality is more multidimensional; it covers a wide range of factors, such as temperature, humidity, various indoor air pollutants and ventilation (Sala et al., 2001; Stipe, 2015), and all of these can cause voice symptoms either alone or in a combination. For instance, if the relative humidity (RH) that is too high or too low, the viscosity and stiffness of the laryngeal mucosa increases significantly which may affect voice production (Hemler et al., 2001) and in turn the temperature directly affects the relative humidity. Moreover, at the same time a low relative humidity causes dryness and irritation of the respiratory track, and this makes individuals more susceptible to infections, however, dry air prevents the growth of harmful microorganisms like mold, bacteria, and viruses. It can therefore be stated that the RH levels outside the optimal range (40–60%) can have a significant impact on health (Guarnieri et al., 2023). In addition, as biological or chemical contaminants in the indoor air can also cause inflammatory or irritating reactions on the mucous membranes of the respiratory tract (Feierabend & Shahram, 2009), a well-functioning ventilation system is necessary as it removes or dilutes the indoor air contaminants and at the same time controls the temperature and humidity in buildings (Heseltine & Rosen, 2009). Based on the recent findings, indoor air quality is the most important and dominant factor influencing overall IEQ in health care environments (Budaiwi et al., 2022).

2.2.2 Other risk factors for hoarseness

Lifestyle risk factors are personal behaviors associated with an individual's lifestyle that are associated with morbidity, for example, smokers are at a higher risk of contracting chronic laryngitis as well as various cancers. It is well-known that smoking irritates the vocal folds and dries out the mucous membranes of the vocal folds, which can eventually lead to inflammation of the vocal folds and voice changes. (Byeon & Cha, 2020). However, cigarette smoking has decreased in the past two decades in Finland as well as worldwide. In 2020, 22% of the world's population (WHO, 2020) and 12% of Finnish population smoked daily (THL, 2022). Based on the literature review by Nilan et al. (2019), 18% of health care workers were smokers, however, the data was lacking from many countries, including from Finland.

Laryngitis and the subsequent hoarseness can also be the result of allergens or other irritants from home, such as dust, dust mites, mold, or pet dander (Cummings et al., 2013; Dworkin, 2008). There is no previous information about the living arrangements of health care personnel as regards possible moisture damage at home or having pets. However, generally, it has been estimated that 15% of detached houses in Finland have moisture damage (Salmela, 2022) and according to Statistics Finland (2020), every third Finnish household has a pet.

2.2.3 Work-related hoarseness

Oral communication plays an important role in everyday interaction, and for many, voice is not only a means of communication, but also an essential means of work performance. Most of the existing studies that have investigated the occupational risk for the development of voice disorders have focused on professional voice users such as teachers and singers. Even though healthcare professionals are classified as moderate voice user (Vilkman, 2000), they still spend about half of their working time in direct patient care which includes communication with patients as well as often with their relatives too. (Johnsson et al., 2018). In health care environment, the oral communication is a primary way in transmitting vital information; answering questions, to discuss the treatment plan, give instructions, in communication with colleagues in addition to participation in group meetings and group discussions (Beyea, 2004). The communication with the patient and coworkers sometimes occurs behind a plexiglass or a face mask, or for instance the patient has impaired hearing which force personnel to speak even louder to be heard (Heider et al., 2021; Johnsson et al., 2018; Ribeiro et al., 2022; Song et al., 2023). In addition to the abundant vocal load, other studies have shown that many other physical conditions in workplaces also increases the risk of voice disorders; for instance, in health care environment, cleaning products, disinfection and sterilizing agents, pharmaceuticals, anesthetic gases and surgical smoke are all associated with respiratory adverse health effects (Choi, 2017; Dascalaki et al., 2008; Gerster et al., 2014; Kurth et al., 2017).

Despite the importance of clear oral communication ability in healthcare, occupational voice disorders in that specific environment have received little research attention; There are two separated epidemiological studies in which nurses were used as a control group while the main studies were focused on the prevalence of voice disorders in teachers. Based on the findings by Sala et al., the prevalence of hoarseness among nurses is much lower than among teachers, being 10 %. (Pekkarinen et al., 1992; Sala et al., 2001). In a population-based study, Lyberg-Ålander et al. (2019) found prevalence of voice disorders among health professionals to be 11.8%, however, none of the before mentioned studies investigated hoarseness specifically, but voice disorder in general. In a study by Heider et al. (2021), a possible association between voice problems and occupational use of face masks was reported; during the COVID-19 pandemic, nearly 33% of healthcare workers have had a problem with their voice. Due to the front-line nature of healthcare professionals work, they have an increased risk of other respiratory infections in addition to COVID-19 and therefore wearing of personal protective equipment such as FFP3 or surgical masks is an everyday necessity (Macintyre et al., 2014; Tran et al., 2012).

Although the risk of voice disorders for health care professionals has not been considered to be particularly high compared to many other professional groups (Lyberg-Åhlander et al., 2019; Mori et al., 2017; Vilkman, 2000), almost all the main risk factors for hoarseness are present in their everyday work.

3 Aims

The purpose of this thesis was to study the prevalence of hoarseness among healthcare personnel in general. The point of view was in self-assessed hoarseness as a single symptom. In addition, to discover the possible risk factors for hoarseness in their working environment together with the predisposing indoor environmental risk factors. In the follow-up studies, we aimed to investigate changes in prevalence of hoarseness and the effects of building renovations on this prevalence.

Study I

The aim of the first study was to determine (1) the current prevalence of self-assessed hoarseness among nurses and (2) to identify the potential environmental risk factors in their working environment.

Study II

The aim of the second study was to determine the current prevalence of self-assessed hoarseness among the nurses in six different occupational subgroups (registered nurses, primary care nurses, pediatric nurses, laboratory nurses, dental nurses, and midwives) in order to determine whether different occupational subgroups have different environmental risk factors for hoarseness.

Study III

In the third study, the aims were to investigate the possible changes in prevalence of self-assessed hoarseness among health care professionals over the period 2007-2018 and discover potential IEQ risk factors for hoarseness among health care professionals working in different units. In addition, in those buildings where remediation had been carried out due to indoor air problems, the effect of the remediation on the health status was investigated before and after the repairs.

Study IV

The aim of the fourth study was to investigate the occurrence of self-assessed hoarseness among medical staff in Finnish primary health care centers (PHC) and to find potential risk factors associated with the work and the work environment. The second aim was to discover if the pathophysiological mechanisms of the voice problems can be revealed with current immunological and allergological tests. The third aim was to discover whether the remediation of the buildings influenced the prevalence of hoarseness. This was performed through a 2-year follow-up with a study population who had continued in their current jobs and current workplace.

4 Materials and Methods

4.1 Study population

The study population for this study consist of health care personnel working in Finnish healthcare. The data for Studies I and II was collected in collaboration with two trade unions, Super (The Finnish Union of Practical Nurses) and Tehy (Union of Health and Social Care Professionals in Finland). The largest group of members of these trade unions of are registered nurses and practical nurses. In the follow-up studies (III and IV), all employees in these participating units/hospitals were invited to participate in the study and both studies were conducted as open cohorts. The summary of materials and methods are presented in **Table 2**.

Table 2. Summary of materials and methods.

STUDY N:O	N	STUDY POPULATION	SELECTION CRITERIA	EXCLUSION CRITERIA	METHODS
I	13,560	Members of Tehy	Random sample	Works abroad Retired Unemployed	Health questionnaire
II	15,553	Members of Tehy and Super	Random sample	Works abroad Retired Unemployed	Health questionnaire
III	2,763	All employees in selected units/hospitals	Cluster sample	None	Health questionnaire (open cohort follow-up) Building condition reports
IV	1,022	All employees in selected units	Open cohort	None	Health questionnaire (open cohort follow-up) Building condition reports Skin prick tests Blood samples

4.2 Health questionnaire

In all four studies, the health data was collected with a validated questionnaire based on the MM40- and the Tuohilampi-questionnaires (Savilahti et al., 2005). The MM40-questionnaire is a standardized and validated questionnaire for the employees of workplaces and the questionnaire investigates the subjective indoor quality. It covers factors like temperature, humidity, various indoor air pollutants and ventilation (Andersson, 1998; Reijula & Sundman-Digert, 2004); the Tuohilampi-questionnaire is validated for epidemiological investigations of the respiratory-, skin-, eye-, and non-specific symptoms (Kilpeläinen et al., 2001).

The questionnaire is comprised of 53 questions which are divided into five sections: (1) the work environment, (2) the work arrangements, (3) well-being and job satisfaction, (4) perceived environmental problems at work (draught, dry or stuffy air, the visible signs of the moisture damage, visible mold growth or mold odor, etc.) (MM40) and (5) employees' health status and medical history (respiratory infections and their care, and the use of medication and diseases diagnosed by a physician). Examples of the key questions are presented in **Table 3**. In addition to the conventional background questions such as age, sex, educational level and occupational group, some lifestyle factors were also requested, such as smoking and pet owning. After the first pilot study in 2007 (Study III, pilot phase), questions about work related stress and work overload were added to the questionnaire, but otherwise the questionnaire has remained the same throughout all four studies.

The health data was collected initially by sending questionnaires by post (Study III, pilot phase), but from the beginning of 2008 these were sent via e-mail. In Studies I and II, the trade unions forwarded the survey through their own membership registers because of their privacy protection policies.

Table 3. Examples of the key questions from the health questionnaire.

THEME	QUESTION	RESPONSE OPTIONS
Hoaseness	Have you had hoarseness in the last 12 months?	1) Never, almost never 2) once or a few times per month 3) every week 4) daily or almost daily
Infections	Have you had any infectious diseases in the last 12 months? If you answer yes, estimate how many infections there are in total • sinusitis • rhinitis • common cold	1) Yes. How many? _____ 2) No
Medical history	Do you have (or have you had) any disease or condition diagnosed by a doctor? • asthma • allergic rhinitis	1) Yes 2) No
Environmental factors	Has any of the following factors bothered you in your workplace during the past 12 months? • draft • room temperature too high • variable room temperature • room temperature too low • dry air • stuffy indoor air • moist air/ high humidity • inadequate ventilation • smell of mold or cellar • sewer odor • other unpleasant odors • tobacco smoke • noise	1) never, almost never 2) once or a few times per month 3) every week 4) daily or almost daily
Respiratory/eye/skin symptoms	Have you had the following respiratory symptoms or eye symptoms in the past 12 months? • blocked nose, rhinitis • cough • dyspnea • wheezing • eye irritation • facial skin irritation • skin irritation	1) never, almost never 2) once or a few times per month 3) every week 4) daily or almost daily
Stress	Have you experience work-related stress during the past 12 months? Have you experience work overload during the past 12 months?	1) yes, most of the time 2) yes, sometimes 3) only rarely 4) never

4.3 Buildings

In Studies III and IV, all the buildings were inspected by qualified trained construction engineers. According to the national guidelines microbial samples were taken from buildings’ structure and the samples were cultivated on three agar plates for 7–10 days and the resulting colonies were counted and identified with light microscopy by a trained environmental microbiologist in a laboratory with accreditation of the Finnish Accreditation Service (FINAS) (Välikylä, 2009). The classification of buildings as an "exposed building" or "reference building" was done by external experts. Exposure assessment data was obtained from the employers or from the owners of the buildings.

Before the follow-ups, four of the "exposed buildings" underwent thorough renovations; All existing moisture damages were remediated, structures containing mold were renewed, ventilation ducts were cleaned, and all places and surfaces were cleaned carefully after the renovation.

4.4 Skin prick tests

In the study IV, a skin prick test (SPT) was performed on all volunteers were performed with standard allergen extracts acquired from ALK–Abelló and the same experienced laboratory nurse performed all the tests. All wheals with a diameter of $\geq$ 3 mm were considered positive when the negative control solution was negative. In addition to common environmental allergens, such as pollen and animal dander, tests were also carried out for dust mites, storage mites and micro fungi (molds and yeast).

4.5 Blood samples

In Study IV, blood samples were drawn by a trained laboratory nurse. The immunological samples were analyzed in a local university hospital. Lymphocyte populations were analyzed utilizing flow cytometry and immunostaining with standard fluorescent cellular markers. The immunoglobulin E (IgE) isotype antibodies against moisture indicator molds and actinomycetes were analyzed in the Laboratory Services of the Finnish Institute of Occupational Health (accredited by FINAS according to requirement SFS-EN ISO/IEC 17025:2017) (Finnish Institute of Occupational Health, 2023).

4.6 Data analysis

For Studies I and II, the exclusion criteria comprised those nurses, who had worked abroad, were unemployed or had retired, whereas in Studies III and IV all employees in selected units/hospitals were invited and included. In addition to background questions, such as age, gender, occupational group, smoking, or pet owning, the questions chosen for the statistical analysis in all the studies were questions regarding perceived environmental problems; of all asked the perceived symptoms presented, only hoarseness was reported. For Study II, in the medical history -section, a selection of the potential causes for hoarseness, including asthma, sinusitis, rhinitis, and common cold were also included. Finally, in addition these, perceived work overload and stress were included in Studies III and IV. Furthermore, results of the blood samples and SPTs were taking into count in Study IV.

For the statistical analysis, an ordinal four-point scale for symptoms and perceived environmental problems were merged into two groups: the alternatives “never, almost never” and “once or a few times per month” became “more seldom or never” and “every week” and “daily or almost daily” became “weekly or more often”. In the analysis, the nonparametric tests in the IBM SPSS Statistics v. 25-26 (IBM Corp. Armonk, NY) were used. The p-values between symptoms and different environmental factors were calculated using cross-tabulations and the Chi-Square (χ^2) test. However, in cases where the observed number in the subgroups was <10, the Fisher’s exact test was used instead. In the statistical analysis of the follow-ups (III and IV), dichotomous variables between the cluster samples (non-paired data of exposure group and reference group) were compared with a χ^2-Test. After the follow-up survey, the results prior to remediation were compared with the respective results in the same unit after the repair. The paired data of the same respondent pre- and post-renovation were compared with a McNemar-Bowker’s test. Finally, a logistic regression model was used to control for confounding variables to determine the effect of the remediation.

4.7 Ethical issues

The guidelines of the Finnish Advisory Board on Research Integrity (TENK, 2012, 2023) were followed throughout the whole research project. The most essential ethical principles in this study were respecting the participants’ right of self-regulation, privacy, and data protection. According to the Declaration of Helsinki, all the necessary research permissions were obtained from both participating unions and the ethics committee of the University of Turku (224/13/03/00/14). For the participants, answering the questionnaire following a written request for the study was considered as consent.

5 Results

5.1 The prevalence of hoarseness and its environmental risk factors among nurses (Study I and II)

5.1.1 Participants

Study I is based on the findings of 13,560 health questionnaires collected from the members of Tehy, the largest trade union of health and social care professionals in Finland. The data represents the membership statistics of the union very well (**Table 4**). For Study II, in addition to the material collected from Tehy, a smaller sample (N=1993) from members of SuPer (The Finnish Union of Practical Nurses) was included. The largest groups of members in these trade unions are registered nurses, practical nurses, and public health nurses. Study II is based on a total of 15,553 returned health questionnaires of which 808 (5.2%) answers were received from men and 14,467 (92.7%) were from women. A small number of respondents (n=254, 1.6%) did not reveal their age or gender. The participants were predominantly non-smokers (91.5%) with an average age of 44.9 years. Based on the reported occupations, participants were divided into six subgroups; registered nurses, primary care nurses, pediatric nurses, laboratory nurses, dental nurses, (which included both mouth hygienists and dental nurses) and midwives. The distribution of the occupations of the Study II participants is presented in **Table 5.**

Table 4. Comparative table about the collected data in Study I and Tehy's statistics.

		COLLECTED DATA	TEHY STATISTICS*
Gender (%)	Female/Male	94.3/5.6	92.2/7.8
Occupational groups	Registered nurse	49.9	50.3
	Practical nurse	10.6	10.5
	Public health nurse	6.4	6.1
	Biomedical Laboratory Scientist/ Laboratory assistant	5.2	5.1
	Physiotherapist	4.5	5.8
	Pediatric nurse	4.1	4.9
	Dental assistant/ Dental hygienist	5.5	4.9
	Midwife	3.9	2.5
	Radiographer	3.0	2.5
	Mental nurse	0.9	1.3
	Paramedic	0.8	0.7
	Others	5.2	5.4

* https://www.tehy.fi/fi/tehy/keita-varten updated 18.9.2017 (Accessed 27.10.2017)

Table 5. The distribution of the occupations of the study II participants.

OCCUPATIONAL SUBGROUP	MEN	WOMEN	TOTAL	SMOKERS (%)
Registered nurses	421	7294	7715	7.9
Practical nurses	195	3188	3383	15.4
Laboratory nurses	18	677	695	4.3
Pediatric nurses	7	664	671	5.4
Midwives	1	554	732	4.6
Dental nurses	5	727	540	5.0
Total	806	14467	15273	8.5

5.1.2 Prevalence of hoarseness

Based on Study I findings, 30% of respondents had had hoarseness weekly or more often over the past 12 months. Its prevalence was more common in women (30%) than men (22%). In 69% of cases, the symptom disappeared or were alleviated when the participant was outside the workplace. The corresponding findings were similar in Study II. However, we found significant differences in the prevalence of hoarseness among different occupational subgroups; hoarseness occurred 28.7% among registered nurses, 32.2% among practical nurses, 24.5% among laboratory nurses, 31.8% among pediatric nurses, 37.7% among midwives, and 34.7% among dental nurses.

5.1.3 Environmental risk factors for hoarseness

Overall, more than half of the respondents indicated that they perceived environmental problems in their work either weekly or more often during the past 12 months. Dry air, stuffy air, and inadequate ventilation were the most common perceived risk factors in both studies, although there was a significant difference among sub-groups which are presented in **Table 6**. A multiple logistic regression analysis was used to explore the predictors for hoarseness. The associations between perceived environmental problems and hoarseness are presented in **Table 7**.

Table 6. Weekly or more often perceived indoor air related environmental problems during the previous 12 month (n (%) of the respondents).

	STUDY I				STUDY II							
Environmental problem	**women n, (%)**	**men n, (%)**	**total n, (%)**	**p-value**	**registered nurses n (%)**	**practical nurses n (%)**	**laboratory nurses n (%)**	**pediatric nurses n (%)**	**midwives n (%)**	**dental nurses n (%)**	**total n, (%)**	**p-value**
Draft	4139 (35)	224 (32)	4363 (35)	**0.002**	2685 (36.1)	414 (30.2)	283 (**42.5**)	193 (35.0)	202 (37.5)	146 (29.1)	4418 (34.9)	**<0.001**
Room temperature too high	3455 (29)	208 (29)	3663 (29)	0.74	2092 (28.1)	564 (**40.7**)	175 (26.4)	113 (20.5)	174 (31.7)	200 (39.8)	3708 (29.2)	**<0.001**
Variable room temperature	4023 (34)	213 (30)	4236 (34)	**0.002**	2576 (34.7)	493 (36.0)	189 (29.0)	176 (31.6)	208 (**38.6**)	186 (37.6)	4294 (33.9)	**<0.001**
Room temperature too low	2722 (23)	112 (16)	2834 (23)	**<0.001**	1778 (24.0)	248 (18.5)	137 (21.3)	116 (21.5)	146 (**27.5**)	94 (19.5)	2832 (22.9)	**<0.001**
Dry air	6506 (55)	336 (27)	6842 (54)	**<0.001**	4264 (56.7)	745 (53.9)	308 (46.5)	261 (46.9)	372 (**68.1**)	200 (41.1)	6930 (54.3)	**<0.001**
Stuffy indoor air	6815 (56)	333 (47)	7148 (56)	**<0.001**	4188 (55.1)	918 (64.6)	320 (47.3)	300 (52.1)	378 (**69.0**)	298 (56.9)	7239 (55.7)	**<0.001**
Moist air/ high humidity	1146 (10)	71 (10)	1217 (10)	0.68	708 (9.6)	227 (**16.9**)	35 (5.5)	29 (5.5)	46 (8.6)	49 (10.4)	1233 (9.9)	**<0.001**
Inadequate ventilation	6297 (52)	296 (41)	6593 (52)	**<0.001**	3862 (51.1)	849 (**60.9**)	274 (41.1)	294 (51.9)	334 (60.8)	302 (58.8)	6678 (51.8)	**<0.001**
Smell of mold or cellar	2908 (24)	141 (20)	3049 (24)	**0.002**	1773 (23.6)	1004 (**30.7**)	116 (17.5)	136 (22.2)	161 (29.6)	142 (28.2)	3731 (25.3)	**<0.001**
Sewer odor	2748 (23)	134 (19)	2882 (23)	**<0.001**	1634 (21.7)	976 (29.8)	115 (17.1)	167 (26.2)	166 (**30.3**)	132 (25.9)	3505 (23.7)	**<0.001**
Other unpleasant odors	3917 (33)	208 (29)	4125 (33)	**<0.001**	2524 (33.8)	571 (**41.3**)	172 (26.1)	126 (22.8)	190 (35.1)	163 (32.7)	4177 (32.9)	**<0.001**
Tobacco smoke	1255 (11)	111 (16)	1366 (11)	**<0.001**	835 (11.2)	235 (**17.3**)	35 (5.4)	18 (3.4)	40 (7.4)	38 (7.8)	1381 (10.9)	**<0.001**
Noise	5060 (43)	270 (38)	5330 (43)	**<0.001**	2911 (39.1)	651 (47.5)	323 (48.4)	432 (**76.2**)	228 (42.3)	30 (60.4)	5405 (42.6)	**<0.001**

Table 7. Odds ratios (OR) for hoarseness when exposed to different environmental problems weekly or more often, and when adjusted for age, gender, smoking, and occupational subgroups.

ENVIRONMENTAL PROBLEM	OR The frequency of exposure:		OR (95% CI)	P-VALUE
	more seldom/ ever	weekly/ more often		
Draft	1	1.46	1.29–1.64	**<0.001**
Room temperature too high	1	1.51	1.87–2.22	**<0.001**
Variable room temperature	1	1.48	1.31–1.67	**<0.001**
Room temperature too low	1	1.41	1.62–1.95	**<0.001**
Dry air	1	2.18	1.89–2.50	**<0.001**
Stuffy indoor air	1	3.00	2.57–3.50	**<0.001**
Moist air/ high humidity	1	1.96	1.67–2.31	**<0.001**
Inadequate ventilation	1	2.34	2.04–2.68	**<0.001**
Smell of mold or cellar	1	3.00	2.68–3.36	**<0.001**
Sewer odor	1	2.14	1.91–2.40	**<0.001**
Other unpleasant odors	1	1.89	1.68–2.14	**<0.001**
Tobacco smoke	1	1.54	1.30–1.81	**<0.001**
Noise	1	1.17	1.04–1.32	**<0.01**

5.1.4 The connection of the respiratory symptoms to the variations in the prevalence of hoarseness

In Study II, we looked for possible connections to the variations in the prevalence of hoarseness by comparing the medical history of the participants. Asthma, allergic rhinitis, and common respiratory infections were chosen for further analyses. The above-mentioned diseases were further examined according to whether the symptomatology was associated with hoarseness or not. (**Table 8**).

According to the data, asthma with hoarseness was reported significantly more often (p=0.01) than asthma without hoarseness. However, there were no significant differences between subgroups in this regard. Although the dental nurses had a notably lower prevalence (p<0.05) than the other groups for asthma without hoarseness, but other prevalence were relatively evenly distributed between the other subgroups. Moreover, in the prevalence of allergic rhinitis with or without hoarseness, there were no significant differences observed between subgroups.

The prevalence of common cold with hoarseness was significantly higher than common cold without hoarseness (p= 0.001) and it was also distributed quite evenly between subgroups. Having a common cold without hoarseness was most often reported by midwives and least often by dental nurses.

Table 8. The association of asthma, rhinitis, and common respiratory infections with reporting of hoarseness in different occupational groups.

DIAGNOSED DISEASE OR RESPIRATORY INFECTION DURING THE PREVIOUS 12 MONTHS	REGISTERED NURSES N (%)	PRACTICAL NURSES N (%)	LABORATORY NURSES N (%)	PEDIATRIC NURSES N (%)	MIDWIVES N (%)	DENTAL NURSES N (%)	P-VALUE BETWEEN OCCUPATIONAL GROUPS	P-VALUE BETWEEN SYMPTOM / DISEASE GROUPS
Respondents with asthma, no hoarseness	477 (10.3)	242 (11.0)	52 (10.2)	46 (11.5)	37 (11.5)	21 (6.1)	**0.04**	**0.01**
Respondents with asthma and hoarseness	453 (24.2)	253 (24.2)	38 (23.0)	51 (27.4)	61 (31.4)	29 (15.9)	0.13	
Respondents with hoarseness, no asthma	1416 (25.4)	794 (28.9)	127 (21.7)	135 (27.6)	133 (31.9)	153 (32.2)	**0.001**	
Respondents with allergic rhinitis, no hoarseness	966 (20.8)	441 (20.0)	99 (19.4)	91 (22.8)	61 (19.0)	61 (17.8)	0.35	0.30
Respondents with allergic rhinitis and hoarseness	621 (33.2)	338 (32.3)	58 (35.2)	62 (33.3)	54 (27.8)	59 (32.4)	0.59	
Respondents with hoarseness, no rhinitis	1248 (25.3)	709 (28.7)	107 (20.7)	124 (28.6)	140 (35.0)	123 (30.4)	**0.001**	
Common cold, no hoarseness	2964 (71.6)	623 (75.1)	316 (69.1)	219 (70.0)	227 (77.5)	193 (65.4)	**0.001**	**0.001**
Common cold and hoarseness	1365 (82.7)	334 (84.6)	114 (78.1)	115 (82.7)	141 (82.5)	121 (78.1)	0.30	
Hoarseness with no common cold	286 (19.6)	61 (22.8)	32 (18.5)	24 (20.3)	30 (31.3)	34 (25.0)	**0.05**	
Acute sinusitis, no hoarseness	810 (18.3)	183 (20.8)	76 (15.6)	68 (20.1)	53 (17.0)	50 (15.6)	0.14	**0.003**
Acute sinusitis and hoarseness	642 (37.6)	169 (42.7)	47 (30.9)	51 (36.2)	59 (32.4)	62 (40.0)	0.06	
Hoarseness, no sinusitis	1066 (22.8)	227 (24.6)	105 (20.4)	90 (25.0)	123 (32.3)	93 (25.6)	**0.001**	

Sinusitis was significantly more often reported with hoarseness than without ($p < 0.01$). However, there were no significant differences between the subgroups regarding the prevalence of sinusitis and whether sinusitis occurred with or without hoarseness. However, a tentative trend was observed in the prevalence of sinusitis with hoarseness; the highest prevalence was found in practical nurses and the lowest in laboratory nurses.

5.2 Changes in the prevalence of hoarseness over the period 2007–2018 (Study III)

5.2.1 Participating units

In total of 2763 employees, 1564 from participating PHC units and 1199 from two hospitals, were participating in Study III. The main characteristics, including the schedule, the number of participants and participating units (reference buildings/exposure buildings), background variables and prevalence of hoarseness, are presented in **Table 9**.

5.2.2 Time trend in the prevalence of hoarseness

In the pilot study, the prevalence of hoarseness in a non-damaged reference ward was 5.9% and in the exposed group 36.1%. In the larger study of PHC units, the respective values were 5.6% and 21.2%. Throughout this study, the prevalence of hoarseness has remained at the same low level in buildings with no IEQ problems (5.9% at the beginning of the study and 4.9% at the end of the study). In the PHC units with IEQ problems, the prevalence of hoarseness was 4–6 times higher (**Table 9**).

In addition to hoarseness, asthma and allergic rhinitis diagnosed by a physician were investigated during the observational period 2007–18. These were both on rather similar levels when those exposed were compared to those not exposed (**Table 9**).

Table 9. Description of the pilot, primary health care units'- and the hospital studies (Phases 1- 3). Crude rates, n (%) of hoarseness and background variables.

	PILOT STUDY (PHASE 1) 2007			PHASE 2 2008-2018				PHASE 3 2011		
	pilot study, exp.	**pilot study, ref.**	**pilot study, total**	**PHC units, exp.**	**PHC units, ref.**	**PHC units total**	**p-value**	**exp. hospital**	**ref. hospital**	**p-value**
No. of buildings	1	1	2	12	4	16		1	1	
Mean age (y)	41.4	43.3	42.0	45.1	43.5	44.9		42.73	42.65	
Men **Women** **Total**	3 (8.1) 34 (91.9) 37	0 18 (100) 18	3 (6) 52 (94) 55	52 (6.1) 804 (93.9) 856	16 (5.9) 256 (94.1) 272	68 (6.0) 1060 (94.0) 1128	n.s.	72 (7.4) 901 (92.6) 973	24 (10.6) 202 (85.0) 226	0.074
Smokers	10 (29.4)	4 (23.5)	14 (27.5)	102 (14.2)	26 (10.5)	128 (13.3)	**0.01**	54 (5.5)	30 (13.2)	**0.001**
Passive smoking	3 (9.1)	1 (6.7)	3 (5.7)	49 (6.7)	0 (-)	49 (5.2)	**0.001**	29 (2.9)	11 (4.9)	0.15
Work overload	no data	no data	no data	220 (26.9)	63 (25.5)	283 (26.5)	0.36	202 (20.8)	47 (21.1)	0.54
Dry throat	13 (35.1)	3 (16.7)	16 (29.1)	210 (25.5)	26 (11.0)	236 (22.3)	**0.001**	121 (12.5)	33 (14.5)	0.27
Hoarseness	13 (36.1)	1 (5.9)	14 (26.4)	181 (21.2)	15 (5.6)	196 (17.4)	**0.001**	354 (37.8)	49 (22.7)	**0.001**
Pets at home	21 (56.8)	6 (33.3)	27 (49.1)	357 (43.3)	95 (38.1)	452 (42.1)	**0.01**	363 (39.1)	50 (23.3)	**0.001**
Indoor air problems at home	4 (14.8)	4 (22.2)	8 (17.8)	28 (4.9)	19 (8.6)	47 (6.0)	0.054	363 (39.1)	50 (23.3)	**0.001**
Asthma*	4 (10.8)	2 (22.2)	6 (10.9)	76 (9.8)	19 (7.9)	95 (9.4)	0.36	68 (6.9)	19 (8.4)	0.45
Allergic rhinitis*	11 (29.7)	7 (43.8)	18 (32.7)	232 (29.8)	83 (34.3)	315 (30.9)	0.18	145 (14.8)	32 (14.1)	0.79

*Diagnosed by a physician

5.2.3 The effect of the remediations to prevalence of hoarseness

Four buildings with IEQ problems underwent thorough renovations during the follow-up time. All existing moisture damages were remediated, structures containing mold were renewed, ventilation ducts were cleaned, and all places and surfaces were cleaned carefully after the renovation. Following this, the crude prevalence of hoarseness decreased from 16.2% to 11.4%. At the end of the follow-up in the PHC units, the hoarseness experienced by employees in remediated buildings was 11.4% and in the reference group 4.9%. Prior to the renovation, the prevalence of hoarseness was statistically significantly higher compared with the reference building. However, the statistical significance disappeared after the renovation, although the prevalence of hoarseness was somewhat higher than in the reference group with no damage. (**Table 10**). Surveys in the exposed groups and reference groups were performed in the same year in both PHC units with the IEQ problem and the unit with no IEQ problem and no intervention. The time between the before and after renovation surveys was 2-3 years.

Table 10. Description of the main characteristics of the follow-up study (Phase 4): the PHC units before (1) and after the remediation (2). Crude rates (n, %) of hoarseness and background variables.

	EXP. PHC UNITS BEFORE REPAIR (1)	PHC UNITS REFERENCE GROUP (1)	P-VALUE	EXP. PHC UNITS AFTER REPAIR (2)	PHC UNITS REF.GROUP FOLLOW-UP SURVEY (2)	P-VALUE
No. Of buildings	4	4		4	1	
N	275	272		328	102	
Mean age	44.3	44.4		44.2	44.2	
Men **Women** **Total**	26 (9.5) 249 (90.5) 275	16 (5.9) 256 (94.1) 272	0.12	44 (13.4) 284 (86.6) 328	8 (7.9) 93 (92.1) 102	0.13
Smokers	23 (13.4)	26 (10.5)	0.73	31 (10.9)	7 (7.2)	0.27
Passive smoking	26 (9.8)	9 (3.7)	**<0.01**	16 (6.0)	1 (1.1)	0.13
Work over-load	66 (24.1)	63 (25.5)	0.17	65 (22.7)	16 (16.5)	0.76
Sore throat	64 (24.1)	26 (11.0)	**<0.001**	62 (22.6)	8 (9.0)	**0.01**
Hoarseness	44 (16.2)	15 (5.6)	**<0.001**	38 (11.4)	5 (4.9)	0.09
Pets at home	114 (41.5)	94 (38.1)	0.28	117 (40.8)	32 (33.0)	0.32
Asthma*	21 (7.7)	19 (7.9)	0.54	24 (9.0)	8 (8.8)	0.58
Allergic rhinitis*	92 (33.9)	83 (34.3)	0.93	108 (40.3)	35 (38.9)	0.55

*Diagnosed by a physician

5.2.4 Risk factors for hoarseness in PHC units

In the logistic regression model of follow-up data of PHC units with or without IEQ problems, statistically significant factors for hoarseness were age, smoking, allergic rhinitis, asthma and uncorrected IEQ problems in the workplace. Female gender seems to have a higher risk for hoarseness; however, the difference was not statistically significant. The risk of hoarseness decreased with age. Smoking increased the risk of hoarseness. The association between asthma and hoarseness was strong and highly significant, but the confidence interval was wide. Building renovation reduced the risk of hoarseness and uncorrected IEQ problems were a statistically significant risk factor for hoarseness when age, gender, allergic rhinitis, asthma, smoking, and pets were taken into account in a logistic regression model (**Table 11**).

Table 11. The risk factors for hoarseness in PHC units associated with the remediation of the buildings in the follow-up study. OR and 95% confidence intervals in a logistic regression model adjusted for age, gender, allergic rhinitis, asthma, excessive workload, smoking and having pets. (N=757)

	OR	OR (95% CI)	P-VALUE
Age	0.94	0.92–0.97	**0.001**
Gender, female **Male**	1.67 1	0.62–4.48	0.31
Pets **No pets**	0.59 1	0.34–1.02	0.06
Smoking **No smoking**	1.66 1	1.23–2.24	**0.001**
Excessive workload **Less workload**	0.88 1	0.61–1.26	0.49
Allergic rhinitis **No allergic rhinitis**	1.70 1	1.01–2.85	**0.04**
Asthma **No asthma**	8.47 1	4.42–16.23	**<0.001**
Unrepaired ieq problem **Repaired or no damage**	1.88 1	1.36–2.59	**<0.001**

5.3 Prevalence of hoarseness among medical staff in Finnish primary health care centers (Study IV)

5.3.1 Participating units and participants

The data for the Study III was collected from 13 different health care centers of which ten of the buildings were healthcare centers with indoor air problems and three were reference buildings with no major damage. (**Figure 1**) Most of the participants were women (93%) and occupational distribution was as follows: 24% were nurses, 24% assistant nurses, 4% medical doctors, 5% dentists and 7% dental nurses, 8% cleaners and 4% kitchen staff.

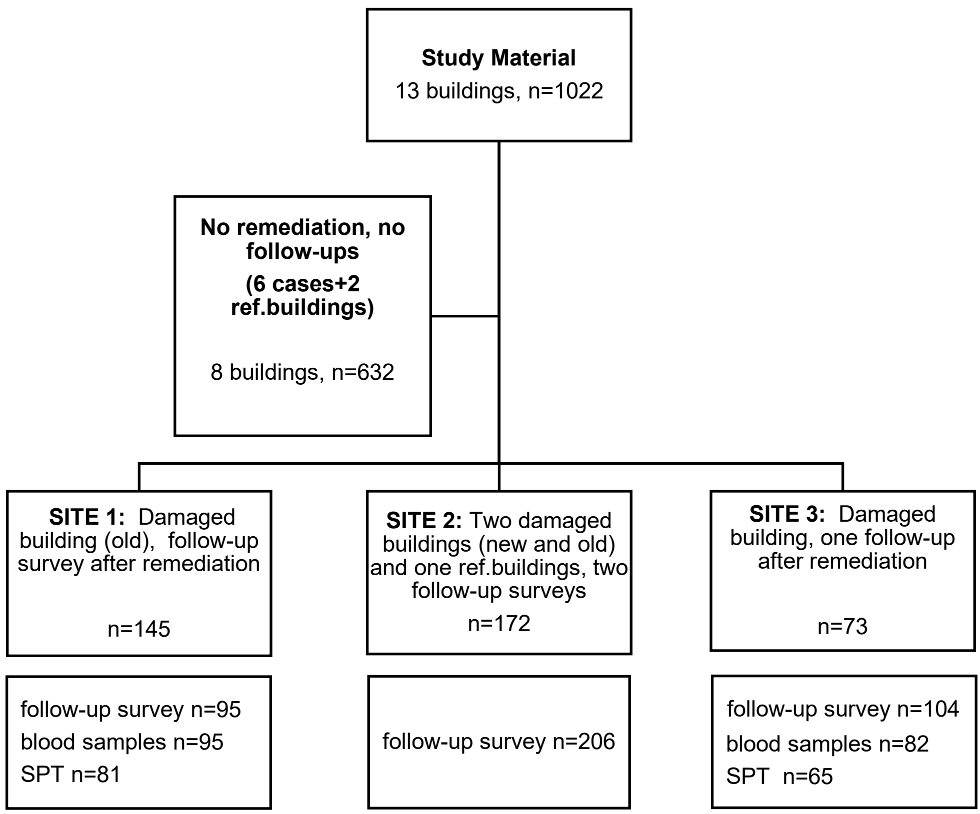

Figure 1. Flow-chart of the collection of the study material.

5.3.2 Perceived indoor air quality before and after remediation

Before the remediation, the most common subjective indoor air-related annoyances were the stuffiness (50%), and the dry air and unpleasant odors (40%). With the exception of noise, the differences between the exposed group and the reference group were statistically significant. After the remediation some of the annoyances diminished (e.g. high temperatures, tobacco smoke, and observations of visible mold), however the annoyances of stuffiness, unpleasant odors and visible dirt increased. The indoor air quality had also become worse in the reference buildings. Nonetheless, most of the annoying factors in the exposure buildings were still at a significantly higher level than in the reference buildings in the follow-ups. All perceived indoor air-related annoyances are presented in **Table 12**.

Table 12. Subjective indoor air quality factors (daily or every week) and signs of moisture damage in the problem and reference buildings. N (%)

	1ST SURVEY			FOLLOW-UP		
	exposure	reference	p-value	remediated (exposure)	reference	p-value
Draught	200 (30.4)	55 (26.8)	**0.02**	67 (47.9)	68 (33.8)	0.07
High temperature	141 (21.8)	35 (16.9)	**0.01**	29 (14.4)	16 (11.5)	**0.01**
Varying temperature	130 (19.8)	35 (17.0)	**0.04**	49 (36.8)	36 (18.4)	**0.001**
Low temperature	57 (9.2)	25 (12.3)	**0.03**	27 (20.3)	30 (15.6)	**0.04**
Dry air	272 (41.0)	65 (31.1)	**<0.001**	62 (45.9)	65 (32.5)	0.07
Stuffiness of indoor air	348 (50.0)	70 (33.3)	**<0.001**	83 (58.9)	67 (32.4)	**0.001**
Unpleasant odor	252 (38.5)	63 (30.9)	**<0.001**	56 (40.6)	33 (16.5)	**<0.001**
Tobacco smoke	44 (7.1)	6 (3.1)	**<0.05**	3 (2.2)	10 (5.2)	**0.12**
Noise	118 (18.9)	45 (22.4)	0.46	37 (27.0)	44 (22.4)	**0.02**
Dust, visible dirt	81 (13.2)	19 (9.5)	**0.01**	45 (33.1)	64 (31.8)	0.87
Visible mold growth	70 (12.1)	8 (3.7)	**0.001**	5 (3.7)	3 (1.5)	**0.01**

5.3.3 Prevalence of hoarseness before and after remediation

Before remediation, the overall prevalence of hoarseness was 17.0%. When viewing the prevalence of hoarseness by professional groups, the percentages were 21% among secretaries, 20% among nurses, physiotherapists, and assistant nurses, 18% among physicians, 16% among dentists, 11% among cleaners and 10% among both dental nurses and kitchen staff. The prevalence of hoarseness was strongly ($p<0.001$) associated with asthma, other respiratory symptoms, irritation of the eyes and skin, and allergic diseases diagnosed by a doctor. Half of the respondents with a sore throat and cough also had hoarseness, and 40% of asthmatics also had voice problems. However, hoarseness did not correlate significantly with either moisture damage at home, current smoking or with having pets. In a logistic regression model when adjusted for age, gender, smoking and asthma, the associations with hoarseness and building damage and unpleasant smells in the indoor air remained statistically significant (**Table 13**).

Table 13. Odds ratios (OR) for hoarseness before remediation, when adjusted for age, gender, smoking and asthma.

	OR	OR (95% CI)
Age	0.96	0.94–0.98
Smoking	1.50	1.18–1.90
Asthma	8.44	4.49–15.84
Damaged building	2.57	1.63–4.05
Unpleasant smells	1.48	1.22–1.79

In the follow-up, the prevalence in hoarseness among all participants was 10%; 9% in reference buildings and 10% in the repaired damaged building. The effect of remediation was clear, prevalence of hoarseness decreased from 19% to 10%. The reduction among nurses and assistant nurses was more evident (7.5% and 8.4%, respectively) than among medical doctors or dentists (10.5% and 10.7%, respectively). Among secretaries and physiotherapists, the prevalence of hoarseness remained relatively high after renovation (15%), but the number of respondents in these groups were very small. However, the differences between occupations were not statistically significant. After the second follow-up, which was four years later, the prevalence was 8%. However, the drop-out rate was high at that point and only 38 individuals responded to the last survey.

After the remediation, hoarseness was still strongly associated with a perceived lack of or insufficient ventilation as before. However, mold odor, visible signs of moisture damage, or leaks, which had a strong correlation with hoarseness before, were no longer significant after remediation.

5.3.4 Allergological and immunological findings

Before the remediation, SPTs from all volunteers were performed with standard allergen extracts acquired from ALK–Abelló. A total of 212 individuals were tested and ALK extract did not show any correlations with the reported hoarseness. On the contrary, respondents with hoarseness often had less SPT positivity than respondents without hoarseness, however, the difference was not significant.

Allergen-specific immunoglobulin E (IgE) tests were performed on 284 individuals of which 2% were IgE positive against mites and 3% positive against molds. However, none of the respondents with hoarseness had IgE positivity against mites or molds.

Immunological samples from 121 participants were analyzed utilizing flow cytometry and immunostaining with standard fluorescent cellular markers. Respondents with hoarseness had significantly higher T-lymphocyte (CD3+) levels than non-symptomatic participants. In addition, T helper -cell ($CD4^+$) (T_H cell) was significantly higher, and the level of the T killer cell ($CD3^+CD4^+$) (T_K cell) population was significantly lower among those with hoarseness compared to those with no hoarseness. No significant difference was observed between these two groups when B lymphocyte ($CD19^+$) populations were compared (**Table 14**).

Table 14. Lymphocyte findings in individuals with or without hoarseness.

LYMPHOCYTE POPULATIONS N=121	MEAN OF CELLS, NO HOARSENESS	MEAN OF CELLS AMONG PERSONS WITH HOARSENESS	P-VALUE	STANDARD ERROR (SE)
T cells (CD3+)	71.71	73.17	**0.03**	1.63
T_h cells ($CD3^+CD4^+$)	43.68	47.63	0.62	1.76
T_K cells ($CD3^+CD8^+$)	27.29	25.49	**0.04**	1.85
B cells ($CD19^+$)	11.00	10.44	0.13	0.80

Respondents who had unpleasant smells in the indoor air at their workplace had significantly higher T-cell levels ($CD3^+$ cells) in the peripheral blood than individuals who were less often or not at all were subject to indoor smells (115 persons tested, $p<0.05$). The difference in $CD3^+$ cells in buildings with technical damage compared to the reference buildings was similar, but not statistically significant ($p=0.26$).

6 Discussion

In professions, where the voice is used constantly or frequently, hoarseness and other voice problems are common; of these professions, teachers have perhaps received the most attention. Among health care professional, to the best of my knowledge, no similar research has been done even though almost all the known risk factors for hoarseness are present in their everyday work and a well-functioning voice is an essential tool for them. This study presents the current situation of the prevalence of hoarseness and its risk factors in the health care field nationwide, and in addition, presents the results of long-term follow-ups, which are extremely important from a problem-solving perspective.

6.1 Methodological considerations

The concept of health care professionals includes all medical, dental, and nursing professions. In Finland, the proportion of nursing professions when registered nurses, practical nurses, midwives, mental nurses, paramedics, dental nurses, and other equivalent professional titles are taken into account is over 82% of all healthcare professionals (OECD, 2021; THL, 2023). Moreover, the degree of organization in the care sector is high and about 90% of those working in the care sector belong to a trade union (Coco & Roos, 2020). Therefore, it was well justified, to cooperate with the trade unions (Studies I and II); it enabled extensive contacts with those working in the field nationwide as well as a large comprehensive random sample sizes. In Studies III and IV, where the interest was targeted to specific buildings, all employees were included which also added medical and dental doctors to this study. It can therefore be stated that all healthcare professionals are represented in this study.

All the data to this thesis was collected with same validated questionnaire, that has been developed specifically for epidemiological research and for evaluating IEQ factors (Andersson, 1998; Kilpeläinen et al., 2001; Reijula & Sundman-Digert, 2004; Savilahti et al., 2005). Both in epidemiological research and in in evaluating various environmental factors, questionnaires are the most commonly used methods (Leccese et al., 2021; Safdar et al., 2016). Surveys are fast and cost-efficient methods which allows a selection of a relatively large sample of people from a predetermined population (Safdar et al., 2016). However, a disadvantage to be noted with questionnaire, especially with online surveys, is the low response rate; the average response rates vary from 20% to 30% (Safdar et al., 2016). In Studies I and II, the questionnaire was forwarded by the trade unions and because of their privacy protection policy the exact number of surveys mailed is not known to us. However, in Studies III and IV, the response rates were at least 50% or more in every survey, which could be considered as to be good.

Because questionnaire presents participants' real perception about environmental factors in their working environment, it is not a diagnostic tool; since the participants' perceptions are subjective and there are different opinions about similar IEQ physical conditions, therefore the results should be considered as indicative. However, who could be better in evaluating the working environment than those who work there on daily basis? A layman will recognize if something is wrong, however identification of the problem is much harder. As a good example of this comes from quite recent Swedish study where subjective IQA factors were compared with measured ones, a perceived "unstable room temperature" was found to be related to higher indoor RH when it was measured and "perceived stuffy air" was found to be associated i.a. with higher RH, higher moisture load, presence of damp foundation, moldy odor and observed mold (Wang & Norbäck, 2022). However, since environmental conditions are known to have a significant impact on employee well-being, productivity, health and safety, complaints of IEQ issues should always be considered as an early indication of a problem that needs to be addressed.

6.2 Hoarseness among health care professionals and its risk factors

Among all the nursing professions, the results suggest that the one-year prevalence of hoarseness was 30%. However, the prevalence of hoarseness between different occupational subgroups was significant; being the lowest among laboratory nurses (24.5%) and the highest among midwives (37.7%). These findings were in line with perceived IEQ problems; the midwives also experienced more annoyance in their working environment than the other groups.

When the prevalence of hoarseness was examined for all employees from specific buildings (Study II and IV), relatively large differences were found in the prevalence of hoarseness among the personnel in the buildings with indoor air problems compared to clean buildings even though the work carrying out in the buildings was similar. In health care centers, the prevalence of hoarseness was clearly shown to be on a lower level than in hospitals and it was also below the average found in this study. Medical doctors and dentists had hoarseness approximately equally often in this material. Even though the assumption was that dental nurses and dentists who are exposed the most to irritating chemicals in their work would experience more hoarseness, but this is not the case according to this material; as secretaries, cleaners, and physiotherapists suffer from hoarseness more often. From this it can be cautiously assumed that chemicals used in dentistry are unlikely to cause large scale voice problems although the work-related respiratory symptoms are frequent in dentalcare (Stoeva, 2021).

When looking at the perceived IEQ problems, more than half of the participants experienced problems related to ventilation, such as stuffy air, perceived insufficient ventilation and/or dry air. The high percentages of problems related to ventilation were not surprising in themselves, because according to an earlier study by Hellgren and Reijula (2011), up to 40% of the ventilation technology in Finnish healthcare units are in a poor condition and in need of major renovation. In addition to ventilation problems, there were also a significant number of perceived defects, such as a `smell of mold or cellar´ or a `sewer odor´. The smell of mold is most likely a sign of mold growing indoors and moisture problem, either as a result of water damage or excessive high humidity (Hurraß et al., 2017; Reponen et al., 2010). Although it is well known that exposure to molds is linked to the varying degrees of health problems, such as mucosal irritations, allergic reactions, and asthma (Heseltine & Rosen, 2009; Hurraß et al., 2017), but primarily, mold growing indoors is always a hygienic problem that should not be found in a healthcare environment. Healthcare facilities requires a healthy IAQ to protect the patients, especially ones with reduced or impaired immunity as well as the healthcare workers from hospital-acquired infections and occupational diseases (Bessonneau et al., 2013; Cabo Verde et al., 2015; El Sharkawy & Noweir, 2014; Fekadu & Getachewu, 2015; Jung et al., 2015; Śmiełowska et al., 2017).

Hoarseness due to short-term vocal abuse, viral upper respiratory infections, allergies, or smoking, are probably the most well-known causes. Among healthcare professionals, the statistically significant risk factors for hoarseness were age, smoking, allergic rhinitis, asthma and unrepaired IEQ problems in the workplace. The role of asthma medication cannot be distinguished from the effect of asthma because hoarseness is a common side-effect of asthma medication, especially corticosteroids (Ihre et al., 2004; Ishizuka et al., 2007). In addition to asthma medication, impaired breathing can affect the quality and production of the voice. Dysphonia and decreased voice quality are common side effects of asthma, affecting one in six asthmatics (Saeed et al., 2018). Nowadays, the unified airway hypothesis proposes that asthma and allergic rhinitis are manifestations of a single inflammatory process and require an integrated diagnostic and therapeutic approach (Licari et al., 2017; Shtraks & Toskala, 2017). Sinusitis, rhinitis, and asthma are closely linked to each other; sinusitis and rhinitis both involve mucociliary dysfunction, tissue edemas and increased mucous production (Rachelefsky, 1999). Sinusitis rarely occurs in the absence of rhinitis and rhinitis can contribute to sinusitis (Decastro et al., 2014; Head & Barnes, 2013; Meltzer & Hamilos, 2011; Rosenfeld & Solomon, 2016; Shaaban et al., 2008; Thomas et al., 2008) and both rhinitis and sinusitis are associated with asthma (Jarvis et al., 2012; Park, 2012; Plaschke et al., 2000; Thomas et al., 2008). Moreover, antihistamines used for allergies have a mucosal drying effect, which may also increase the risk of hoarseness. (House & Fisher, 2017). Therefore, the possible connections to asthma, rhinitis, and common respiratory infections between the prevalence of hoarseness were analyzed. These diseases were further classified according to whether the symptomatology was associated with hoarseness or not. However, among all nursing professionals, the findings between the occupational groups were mainly insignificant. Statistical differences in the prevalence of symptoms/diseases between the different sub-groups were only found in asthma without hoarseness and common colds without hoarseness (Study II). Moreover, in Study III, where the prevalence of hoarseness was compared between exposure - and reference buildings, the levels of prevalence of both asthma and allergic rhinitis were quite similar in both type of buildings. As regards smoking, although it is a significant risk factor for hoarseness, healthcare workers smoke less compared to the Finnish population in general and the smoking trend is decreasing year by year (The Finnish Institute for Health and Welfare, 2021).

Although most hospitals are noisy (de Lima Andrade et al., 2021; Konkani & Oakley, 2012; Xyrichis et al., 2018), which strains the workers' voices and exposes them to hoarseness (Morawska & Niebudek-Bogusz, 2017), although noise was found to be a risk factor, it was not found to be a very prominent one in the healthcare environments in this study. All the other environmental risk factors evaluated seemed to have even stronger associations with the prevalence of hoarseness than noise did.

The two most significant risk factors found for hoarseness were "stuffy indoor air" and a "smell of mold or cellar". As the participants were evaluating the perceived indoor air -related factors, they assessed their perceptions as layman. Therefore, for instance stuffy indoor air can also mean "inadequate ventilation", "unpleasant odors" or "sewer odors", depending on the evaluator's perspective. "The smell of mold or cellar" is a little easier for a layman to recognize, but some of these may also be classified as, for example, an "unpleasant odor". However, the default is that high-quality indoor air has no scent or a neutral scent and therefore to simplify the findings, the problems perceived were considered to be due to ventilation – and/or moisture -problems. The findings of risk the factors are in line with the generally accepted association of indoor air problems and respiratory health (Heseltine & Rosen, 2009; Kanchongkittiphon et al., 2015; Mendell et al., 2011) and also with earlier studies in which a significant correlation has been found between indoor air problems due to moisture damage and hoarseness (Cummings et al., 2013;

Kallvik et al., 2016). Hellgren and coworkers (2011) found a connection with symptoms and insufficient ventilation in hospital buildings and Vertanen-Greis (2020) in school buildings (Hellgren et al., 2011; Vertanen-Greis et al., 2020).

In Study III, the possible changes in prevalence of hoarseness among health care professionals were investigated which to the best of our knowledge, has not been studied previously. Over the period 2007-2018, the health status from all employees in selected units/hospitals was collected using questionnaires and the buildings were classified as "exposed" or "reference" buildings by third-party experts. The effects of repairs on the prevalence of hoarseness were examined by comparing the findings before and after the renovations of the reference buildings. In buildings with no IEQ problems, the prevalence of hoarseness remained at approximately the same level throughout the follow-up period, i.e. between 4.9-5.9%. The levels found were even a little lower than the estimated point-prevalence among adults in general has been estimated to be (Cohen et al., 2012; House & Fisher, 2017; Martins et al., 2016; Pylypowich & Duff, 2016; Roy et al., 2005). However, in buildings with IEQ-problems, the prevalence of hoarseness was found to be 4-6 times higher. After a thorough remediation, was observed to decreased, but was still two times higher than in the reference buildings. The remediation of buildings had a clear and statistically significant beneficial effect on both the prevalence of hoarseness and on perceived IEQ problems; the perceived stuffiness of the indoor air, the unpleasant smells, the too low temperature, and signs of moisture damage had diminished. Similar findings were found in earlier studies on remediations carried out in school buildings and their effect on teachers' health (Patovirta et al., 2004; Putus et al., 2021).

Generally accepted methods for evaluating health effects caused by indoor air problems are currently not available. However, in clinical investigations, immunoglobulin G (IgG) antibodies against microbes related to dampness have been used as a proxy of exposure on group level when seeking the possible risk factors for the development of asthma in adulthoods, and mold specific IgE when screening for allergies (Alenius et al., 2007; Borchers et al., 2006; Hurraß et al., 2017; Wiesmüller et al., 2017). Nevertheless, reliable confirmation of the causal relation between sensitizations to mold, exposure and disease is rare (Hurraß et al., 2017); For instance, IgE-mediated sensitivity to common fungal allergens has been found in only up to 2.8% of Finnish patients with indoor air-related symptoms (Karvala, 2012; Reijula et al., 2003). Therefore, one of the aims of this study was to discover whether the pathophysiological mechanisms of voice problems can be revealed with current immunological and allergological tests. For this, blood samples were drawn, and SPTs were performed on all volunteers. Our study material showed no association with either hoarseness and IgE-mediated hypersensitivity or with hoarseness and SPT positivity, which supports the hypothesis that hoarseness is more often due to irritation of larynx than an IgE-mediated allergic reaction.

Lymphocyte populations were analyzed utilizing flow cytometry and immunostaining with standard fluorescent cellular markers. Lymphocytes are an important part of the human immune system, and they help the body to fight disease and infection; T cells (Regulatory T cells (T_{REG} cells), T_H cells ($CD4^+$) and T_K cells ($CD8^+$)) are involved in cell-mediated immunity, whereas B cells are primarily responsible for humoral immunity (Al-Shura, 2020). In our material, there were lower levels of T_K-cells and higher levels of T_H cells in patients with hoarseness at a group-level and the differences were statistically significant, although both results were in the category of normal findings. Even though this was an interesting finding and worthy of further research, at this point, it is too early to do any speculate or draw any conclusions in this matter. The findings are as yet preliminary, and deeper immunological research like T_H1 and T_H2 distribution with more exhaustive insight into the various leukocyte populations like the T_{REG} and T_H 17 cells are necessary. Moreover, a larger cohort and a longer follow-up of the selected patient groups would be needed (X. Chen et al., 2016; Zambrano-Zaragoza et al., 2014). Nevertheless, to the best of our knowledge, this was the first study to demonstrate a simultaneous association with lymphocyte cell lines, worker-experienced symptoms, and objectively determined work conditions with microbial samples collected by construction engineers.

6.3 Strengths and limitations

The strength of this study is the size of the data and the broad national coverage. All the surveys were conducted with the same validated questionnaire which has been in use for several decades (Andersson, 1998; Savilahti et al., 2005). All the buildings were evaluated according to national guidelines, which are based on the Health Protection Act (Husman, 1999) and the Decree of the Ministry of Social Affairs and Health on Health-related Conditions of Housing and Other Residential Buildings and the Qualification Requirements for Third-party Experts. (545/2015). In addition, the classification as an "exposed building" or "reference building" was done by external experts. The damage in all the buildings with indoor air problems were quite similar to each other. However, the weakness here was that the participants were aware of the exposure, because in most cases the damages were visible, e.g., leakage through the roof, flooding, visible mold growth on surfaces or strong unpleasant smells. In addition, the fact that only self-reported data, with no objective measurements concerning the symptoms were used, was also a weakness; there is always a possibility that the participants overestimated or underestimated their personal symptoms and/or perceived environmental problems. On the other hand, based on earlier studies, the tendency of participants is to rather underestimate than overestimate the environmental problems and/or symptoms when they evaluated environmental factors and possible symptoms related to a perceived environment (Gunnbjörnsdóttir et al., 2006; Platt, 1989).

Although long-term follow-ups are extremely important, follow-up research has its limitations. Perhaps one of the greatest challenges is the requirement of a long-term commitments from all the participants. This was very apparent when trying to find suitable reference buildings, because the employers and employees could not see any immediate benefit from participation as a reference group, which lead to the lower number of participating reference-groups. Fortunately, though, among those who did commit to the follow-ups, the participation rate was the high or very high in almost all the surveys, and they were very committed and co-operative during the field studies. Since the follow-up period was long, there is no way to avoid the fact that the staff at the workplaces will always be subject to change, some retire, some change jobs, etc. Therefore, this study was conducted as an open cohort study where the entire work force A in time point 1 were compared to respective group B in time point 2. These materials are considered as independent samples. In every follow-up point, a paired sample analysis was performed always when the respondent could be identified by name. The statistical analysis of paired observations gives stronger statistical power than comparison of the larger study material at time points 1 and 2. We were also interested of the health of 'new' workers entering the cohort, how they would consider their health status in the remediated building. By following solely, the original population at time point 1, would possibly lead to bias in the results due to so-called 'healthy worker effect' (Chowdhury et al., 2017).

6.4 Implications

Although the IEQ problems in Finnish hospitals and health care units have been recognized since the mid-1990s, some improvements have been made to correct the situation, there is still much to do. According to the results, more than half of the respondents still indicated that they perceived environmental problems in their work weekly or more often. Based on that, it can be stated, that the IEQ problems are still current and a real risk for the voices of healthcare professionals. This thesis shows that more protective measures are required from employers who are ultimately responsible for the health and safety of their employees. To ensure health and safety working conditions, repairs to ventilation systems are needed, and possible moisture damage and maintenance deficiencies should be repaired.

Although hoarseness is rarely a sign of a serious illness, it still may have significant impact on the people voice-related quality of life and limit their productivity (House & Fisher, 2017). In the health care environment, the deterioration of speech intelligibility among personnel is also a matter of patient safety. Therefore, hoarseness is something which cannot be ignored, but instead it should be taken into consideration both as an occupational and a health problem. Proactively supporting the working community and employees' ability to work is in everyone's best interest. Regular monitoring of IEQ could be recommended. In solving IEQ problems, it is important to

1) utilize the expertise of occupational health care,
2) use indoor climate experts to find out the condition of the building and interpret the results as well as carry out the corrective actions according to the prepared-plan and schedule, and
3) monitor the effect of the made repairs on the health of the employees.

Since a well-functioning voice is a key aid for healthcare professionals, it would be important for them to be aware of risk factors, speech in general and voice training. As a preventive measure to reduce the risk of voice problems, voice training should be included in the education of healthcare professionals. Occupational health care should enable voice coaching as a part of primary prevention.

6.5 Suggestions for future research

In a field of research, there is lack in studies about hoarseness or other voice problems among health care professionals in general. More research is needed, and it should also be better focused on buildings, professional groups, and work tasks. As a problem-solving perspective, more follow-up research is needed. In addition to the environmental factors addressed in this study, there are many other work-related exposures which are also known to cause irritation or respiratory symptoms, such as various cleaning chemicals or drug aerosols, or airborne chemical substances during different treatments (El-Helaly et al., 2016; Polovich & Gieseker, 2011; Stoeva, 2021). Therefore, there is a need to investigate other possible work-related risk factors in the health care field. However, since considerable numbers of units are struggling with ventilation problems, ventilation deficiencies must be corrected before other risk factors can reliably be investigated.

7 Conclusions

The overall prevalence of hoarseness among healthcare professionals is relatively high, at 30% according to this study. However, the variations in prevalence of hoarseness are significant among occupational subgroups and also in different buildings; the prevalence increases in line with the perceived IEQ problems. Based on this study, the main risk factors for hoarseness are age, smoking, allergic rhinitis, asthma and unrepaired IEQ problems in the workplace. All findings support the hypothesis that hoarseness is more often due to irritation of the larynx rather than an IgE-mediated allergic reaction.

Over the ten years of the follow-up, the prevalence of hoarseness had not increased in workplaces with good IEQ; in good IEQ-buildings, the prevalence was even lower than among all adults in general. (Cohen et al., 2012; House & Fisher, 2017; Martins et al., 2016; Pylypowich & Duff, 2016; Roy et al., 2005). However, the prevalence of hoarseness was found to be almost six times higher in buildings with IEQ problems. The renovation of the building reduced the risk of hoarseness as well as the reporting of IEQ problems, although the levels of both were still to some extent higher than in the reference buildings without any known problems.

In order to ensure health and safety working conditions for health care professionals, the ventilation systems must be renovated to meet today's requirements and possible moisture damage and maintenance deficiencies must be repaired (738/2002, 2023).

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