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HASAN BIN SOHAIL

EPIDEMIOLOGICAL STUDIES ON THE ADVERSE HEALTH EFFECTS OF NON-OPTIMUM AMBIENT TEMPERATURES

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ABSTRACT

Non-optimum temperatures have been ranked among the ten leading causes of death worldwide by the Global Burden of Diseases (GBD) 2019 study. However, most of the previous studies have investigated temperature-associated mortality. Scientific evidence on the effects of non-optimum temperatures on morbidity is still scarce, and studies have reported inconsistent results. There have been only a limited number of studies that investigated the association of non-optimum temperatures with health outcomes in Northern Europe. Non-optimal ambient temperatures can also affect the self-perceived health of individuals. To the best of our knowledge, only a few studies have investigated the association of temperature with self-perceived health measures.

The present doctoral thesis study has the following objectives: to investigate the short-term associations of a) heat and heatwaves with cardiorespiratory hospital admissions, b) low temperature and cold spells with cardiorespiratory hospital admissions, c) ambient air temperature with self-perceived health outcomes.

For the first and second objectives, health data was obtained from a Finnish national registry containing information on daily hospital admissions, and daily weather data was provided by the Finnish Meteorological Institute for the years 2001-2017. Our third objective was based on the follow-up study data KORA FIT that was further based on the population-based cohort study KORA (Cooperative Health Research in the Region of Augsburg) Germany, which included participants from Augsburg and the vicinity born between 1945 and 1964. The KORA FIT follow-up study was conducted in 2018/2019. Personal and clinical characteristics, medication intake, and disease history were collected through self-administrated questionnaires, interviews, and physical examinations at the study center.

For the first objective, multivariate Poisson time series regression models were used to evaluate the association of the daily number of hospital admissions with daily mean temperature and heatwaves during the summer months. For the second objective, we used a quasi-Poisson regression with distributed lag non-linear models (DLNM) to investigate the lagged and cumulative effects of daily mean temperature and cold spells on the daily number of hospital admissions in the colder months. For the third objective, DLNM, linear regression, and logistic regression models were used to assess the association of self-rated health with daily ambient temperature during the summer and winter months.

We found that heatwave days were associated with an increased risk of pneumonia admissions and during long or intense heatwaves with total respiratory admissions in the oldest age group (≥75 years). There were also suggestive positive associations between heatwave days and admissions due to myocardial infarction and cerebrovascular diseases. In contrast, the risk of arrhythmia admissions decreased during heatwaves. The low wintertime ambient temperature was also associated with an increased risk of hospitalization for myocardial infarction in the whole population. An increased risk of hospital admission for respiratory diseases and chronic obstructive pulmonary disease was observed only in the ≥ 75-year-old age group. There was an independent effect of cold spell days only for asthma admissions in the all-ages group. We found no adverse association between

heat or cold and self-perceived health measures. Nevertheless, low air temperature had a significant protective association with the EQ-5D dimension “usual activities,” implying a potential protective effect of cold weather on daily functioning.

In conclusion, heatwaves, rather than single hot days, are a health threat affecting morbidity even in a Northern climate. Additionally, cold temperature increases the need for acute hospital care due to myocardial infarction and respiratory causes during winter in a northern climate. However, there was no evidence of daily mean air temperature affecting participants' self-perceived health status. Health authorities should make prevention plans for people of all ages, especially older people, to reduce the health impacts of non-optimal temperatures.

Keywords: ambient temperature, hospital admissions, cardiovascular diseases, respiratory diseases, self-rated health, health-related quality of life, heatwaves, cold spells

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Kuopio, 2023
Hasan Bin Sohail

LIST OF ABBREVIATIONS

NO_2	nitrogen dioxide
O_3	ozone
PM_{10}	particulate matter (aerodynamic diameter ≤ 10 μm)
$PM_{2.5}$	particulate matter (aerodynamic diameter ≤ 2.5 μm)
CVD	cardiovascular diseases
MI	myocardial infarction
IHD	ischemic heart disease
COPD	chronic obstructive pulmonary disease
RH	relative humidity
BP	barometric pressure
DLNM	distributed lag non-linear model
HRQoL	health related quality of life
EQ-5D	EuroQol-5 dimension
EQ-VAS	EuroQol Visual Analogue Scale
SRH	Self-rated health
CSRH	Comparative self-rated health
BIC	Bayesian Information Criterion
IPCC	Intergovernmental Panel on Climate Change

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on data presented in the following articles, referred to by the Roman Numerals I- III.

I Sohail H, Kollanus V, Tiittanen P, Schneider A, Lanki T. (2020). Heat, Heatwaves and Cardiorespiratory Hospital Admissions in Helsinki, Finland. *International Journal of Environmental Research and Public Health*, 17(21): 7892.

II Sohail H, Kollanus V, Tiittanen P, Mikkonen S, Lipponen H A, Zhang S, Breitner S, Schneider A, Lanki T. 2022. Low temperature, cold spells, and cardiorespiratory hospital admissions in Helsinki, Finland. *Air Quality, Atmosphere & Health*, 16, 213-220 (2023).

III Sohail H, Zhang S, Mikkonen S, Breitner S, Wolf K, Nikolaou N, Laxy M, Schwettmann L, Peters A, Lanki T, Schneider A. 2023. Association between ambient temperature and self-rated health in Southern Germany: Results from KORA FIT study.

AUTHOR’S CONTRIBUTION

I) Hasan Sohail performed statistical analyses of the data. The first draft of the manuscript was also written by Hasan Sohail. All authors contributed to the manuscript revisions.

II) Hasan Sohail was involved in designing the study. Hasan Sohail performed statistical analysis. The original manuscript was written by Hasan Sohail. All authors contributed to the manuscript revisions.

III) Hasan Sohail was involved in the conceptualization and study design along with other co-authors. Part of the data management and all statistical analysis were done by Hasan Sohail. Hasan Sohail wrote the original manuscript. All authors contributed to the manuscript revisions.

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1 General introduction

Temperature changes caused by climate change are a serious public health concern. According to a recent report by the International Panel for Climate Change (IPCC), global surface temperatures have increased significantly faster in the previous 50 years compared to any other 50 years (IPCC, 2023). Meanwhile, adapting to the high temperatures may also make people more prone to cold extremes (Arbuthnott et al., 2016). Exposure to non-optimal temperatures has been identified as one of the top ten major causes of death worldwide (Roth et al., 2020). With changing temperatures and extreme weather conditions increasing globally, it is paramount to investigate temperature-associated health burdens.

Exposure to low and high temperatures can adversely affect human physiological mechanisms (Deschenes, 2014). When exposed to heat, the body's thermoregulation mechanisms, such as vasodilation and sweating, work to maintain a core temperature of 37°C by dissipating heat. While vasodilation promotes heat transfer, it may also increase cardiovascular strain. Similarly, sweating helps heat removal but can cause dehydration, exacerbating cardiovascular stress when fluid intake is insufficient (Kurz, 2008). In situations of inadequate sweating due to prolonged heat exposure or dehydration, core body temperature can rise, resulting in hyperthermia (>40°C), leading to protein denaturation, tissue necrosis, and organ failure. Extreme heat can profoundly impact various organs, stressing the cardiovascular system and potentially causing heart failure, particularly in older adults with preexisting cardiac conditions. Additional complications may include acute respiratory distress syndrome, pulmonary edema, muscle breakdown, acute renal failure, and liver failure (Lee et al., 2022; Morris Beker, 2018).

Exposure to low temperature can also cause serious health problems. Exposure to cold triggers vasoconstriction as the initial response to minimize heat loss, preserving core body temperature. Shivering, a secondary defence mechanism, generates heat through muscle contractions to counteract hypothermia, but sustainability relies on metabolic substrates availability. Prolonged cold exposure can deplete these substrates, worsening hypothermia as shivering diminishes. Hypothermia sets in below 35°C, requiring urgent medical intervention to prevent further cooling-induced injuries (Ikäheimo, 2018). In cold environments, inhaling cold and dry air can trigger bronchoconstriction, causing respiratory issues like coughing, mucus production, and wheezing. Those with pre-existing respiratory conditions such as asthma or COPD may experience exacerbated symptoms, potentially necessitating hospitalization due to respiratory distress (D'Amato et al., 2018).

Self-perceived health is a practical health measure which covers all aspects of human health (Stanojevic Jerkovic et al., 2017). Self-reported health scales provide more subjective information which can sometimes better reflect the actual or overall health status than any clinical measurements (Benyamini, 2011). Evidence from scientific literature shows that self-rated health is an effective tool for investigating morbidity and premature mortality (Latham & Peek, 2013; Reile et al., 2017). Only a limited number of studies have investigated temperature-associated self-rated health (Jylhä et al., 2006; Li et al., 2020; van Loenhout et al., 2016), which demands further studies.

There are gaps in current knowledge concerning the effects of ambient temperature on morbidity. Existing literature has mostly focused on the mortality effects of low and high temperatures rather than morbidity (Song et al., 2017). Previous scientific studies on temperature-associated morbidity have exhibited varying results. For example, some studies reported a positive association of cardiovascular diseases with hot days (Ye et al., 2012), while Turner et al. did not report any such association in a meta-analysis (Turner et al., 2012). Likewise, a systematic review found an association between low temperatures and respiratory morbidity (Bunker et al., 2016). However, another study from Denmark reported an association only in elderly people (>80 years) (Wichmann et al., 2011). Given the varying results and limited scientific evidence available, there is a need for further research to understand better the effect of ambient temperatures on different morbidity outcomes.

With this doctoral study project, we aimed to understand better the effects of low and high ambient temperatures on human health. More specifically, we investigated the association of non-optimum temperatures with hospital admissions and individuals' self-rated health. Understanding the effects of temperature on morbidity and self-perceived health could help policymakers formulate effective prevention and adaptation strategies.

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2 Review of the literature

2.1 Climate change and impact of temperature shift on health

There is strong scientific evidence that climate change is happening and is mainly caused by human-induced emissions of greenhouse gases. A recent report from the International Panel on Climate Change (IPCC) has concluded that “Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with the global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020” (IPCC, 2023). The acceleration of global warming has led to a significant increase in the frequency, intensity, and duration of extreme temperature events, particularly heatwaves (Han et al., 2022; Horton et al., 2016; Perkins et al., 2012). This trend is projected to continue, with a four-fold increase in heatwave duration by 2050 and a significant impact on health and adaptation capacity in hotspot areas (Han et al., 2022).

As climate change is happening globally, European weather conditions are also transforming (IPCC, 2014). The heatwaves of 2003 and 2010 had significant health and socioeconomic impacts in Western and Central Europe (Fischer & Schär, 2010; Schär et al., 2004). In the summer of 2018, Europe experienced another heatwave that was worse than previous ones (Hoy et al., 2020). With the increase in average temperatures, the distribution of temperature shifts upwards. Consequently, heatwaves are becoming more frequent and intense. Further increase in the duration, intensity, and frequency of extreme temperature events is projected for the future (IPCC, 2023). Ruosteenoja et al. (2023a) projected that southern Europe will experience greater increases in both the severity and duration of heatwaves than Europe's northern and northwestern regions (Ruosteenoja & Jylhä, 2023a). However, northern European countries like

Finland having cool climate would also have much more severe heatwave burden in future. The annual estimate of intense heatwaves in Finland would increase by 50-80% (Ruosteenoja & Jylhä, 2023b). There is a strong likelihood that Finland's average annual temperature will have risen by 2°C to 3°C compared to current levels by the end of this century (Ruosteenoja & Jylhä, 2021).

Despite the concerns about global warming and rising temperatures, it is important to note that subnormal temperatures are still primary drivers of temperature-related mortality (Gasparrini et al., 2015). Additionally, the global increase in temperature doesn't necessarily mean the disappearance of low temperatures and their impact on human health in the future (Díaz et al., 2019; Gasparrini et al., 2015). Climate change diminishes temperature variability by accelerating the warming of cold extremes more rapidly than hot extremes, as evidenced by projections indicating a reduction in diurnal temperature ranges, particularly during colder seasons (Ruosteenoja & Jylhä, 2021). However, Gasparrini et al. (2015) reported that most of the temperature-associated deaths are caused by moderate cold or heat rather than by extreme temperature events (Gasparrini et al., 2015). This implies that probably the primary mechanism underlying temperature-related mortality is the exacerbation of existing health conditions due to non-optimal temperature conditions, rather than hyperthermia or hypothermia. Non-optimal temperatures can cause physiological strain on individuals, exacerbating underlying health conditions and could subsequently lead to mortality.

There is a difference between a single day of heat or cold and sustained periods of extreme temperature. Epidemiological studies investigating the effects of temperature on health outcomes usually characterize the exposure in two ways, i.e., a) daily ambient temperature (as a continuous temperature variable), and b) sustained period of high or low temperature, i.e., heatwaves and cold spells. The effect of a single hot or cold day and sustained period of extreme temperatures (heatwaves and cold spells) can be different from each other, as reported in previous epidemiological literature (Basu, 2009; Conlon et al., 2011; Hajat et al., 2007; Wang et al., 2012).

2.2 Commonly used epidemiological study designs

Environmental epidemiology is mainly defined by the National Research Committee on Environmental Epidemiology as “the study of the effects on human health of physical, biological and chemical factors in external environment, broadly conceived”(Environmental Epidemiology, 1991). There are different study designs to study the effects of temperature as an environmental exposure.

2.2.1 Cohort studies

In cohort studies, a group of persons or sometimes different groups are included with diverse types of exposures of interest. These groups are called cohorts and are observed for a certain period to investigate the association of suspected risk factors and the occurrence of certain health outcome(s). Cohort studies are better suited for investigating the long-term effects of temperature (Ren et al., 2022; Sun et al., 2018; J. Wang et al., 2023). These studies can be retrospective or prospective. Retrospective studies investigate outcomes with exposures that occurred earlier. Prospective cohort studies measure the current exposure, and then participants are followed for a certain period (Epidemiology & Sciences, 1997). However, the use of cohort study designs in environmental epidemiology poses some limitations as well. Cohort studies can be costly and time-consuming. For example, collecting data on health outcomes, temperature, and other environmental exposures for a large cohort may require intensive resource utilization. Moreover, controlling all potential confounders, especially time-varying confounders such as air pollution or access to health care services, would be difficult. The generalizability of results from cohort studies to the entire population can be challenging, especially if the cohort is selected based on specific criteria. Cohort studies can provide evidence-based information on associations between exposure and outcomes; however, causality can’t be concluded as it requires further information.

2.2.2 Time series studies

Time series studies investigate the association of time-varying environmental exposures with counts of time-varying events (Bell et al., 2004). They are considered a type of ecological study because population-level outcomes and exposure levels are investigated (Wakefield & Salway, 2001). This study design is usually used for investigating short-term effects of environmental exposures such as air pollution or weather variables on health outcomes (Basu, 2009; Bhaskaran et al., 2010). Time series regression studies have been commonly used to investigate the short-term association of temperature with health outcomes such as disease-specific hospital admissions. Usually, in time series studies, data is available at regular intervals. Time series data can have seasonal or long-term patterns, time-varying confounding factors, and delayed (lagged) associations between exposure and outcome. Therefore, time series regression methods adjust for time-varying factors (Bhaskaran et al., 2013). This study design can help to investigate temporal associations. However, like other observational studies, time series studies cannot establish causation.

2.2.3 Cross-sectional studies

A cross-sectional study is a kind of observational study design that provides contemporary information about the health status of the population at a specific point in time. These studies are used to investigate the prevalence and distribution of certain conditions and behaviours within a population. Cross-sectional studies are usually quicker and more cost-effective than longitudinal studies. These kinds of studies are useful for hypothesis testing and investigating associations. Several previous studies have used a cross-sectional approach to investigate temperature-associated morbidity (Ae et al., 2008; Amiri et al., 2022). However, this type of study design cannot be used to determine the cause-and-effect relationships. Multiple factors usually influence the outcomes in cross-sectional studies and require the inclusion of numerous covariates (Epidemiology & Sciences, 1997).

2.2.4 Case-crossover studies

The case-crossover study design is best suitable for investigating the intermittent exposures with immediate and transient effect on risk (Maclure & Mittleman, 2000). In a case-crossover design, participants are selected from the cases. The inference is estimated by comparing the exposure of each individual subject (Jaakkola, 2003). This approach compares exposure frequencies immediately preceding the onset of outcomes with control times, effectively using each case as its own control. However, it is essential to address the issue of non-exchangeability which can lead to confounding (Mittleman & Mostofsky, 2014). Many previous studies have used case-cross over study design to investigate the temperature-associated health effects (Guo et al., 2011; H. Lee & Yoon, 2024; Saucy et al., 2021; Tong et al., 2012). Using the case-crossover study design, researchers can effectively examine the immediate and transient effects of temperature on health outcomes, providing valuable insights into the mechanisms and risks associated with temperature-related health effects.

2.3 Effect of temperature on human health

2.3.1 Temperature-associated mortality

The effect of temperature on human mortality is a serious public health concern. Studies on temperature-associated mortality across different regions have reported an increased mortality risk after exposure to low and high ambient temperatures or extreme temperature periods such as heatwaves or cold spells. Globally, it is estimated that non-optimal temperatures contribute to about 7.7% of total mortality. Among these, lower than optimal temperatures constitute 7.3%, while higher than optimal temperatures contribute a smaller proportion, estimated at 0.42%. The study also reported that cold attributed to more deaths as compared to heat

(Gasparrini et al., 2015). A study from China reported that non-optimum temperatures caused 14.3% of mortality, of which 11.6% of deaths were explainable by low temperatures and 2.7% by high temperatures (Chen et al., 2018). Likewise, another study from Finland showed that heatwave days can increase the mortality (Kollanus et al., 2021a). Many other studies from Australia, South Africa, India, the EU, and other regions of the world also found an association between ambient temperature and mortality (e.g. Fu et al., 2018; Hajat et al., 2007; Scovronick et al., 2017). The minimum mortality varies among nations and climates, which indicates populations' adaptation to their place of residence (Näyhä, 2005).

In Finland, mortality exhibits a sharp increase during autumn, peaks during the christmas holidays, and gradually declines towards a trough in August. Mortality rates are lowest at a mean daily temperature of +14°C, with a slow increase observed as temperatures decrease and a steep rise as temperatures increase. The influence of low temperature persists and will remain significant in Finland despite of a decline in cold-related mortality. Approximately 2000-3000 additional deaths occur during the cold season in Finland, with the majority affecting individuals aged 65 years and older, although 20% are at working age. Conversely, the number of fatalities attributed to high temperatures (above +14°C) in a normal year in Finland ranges from 100 to 200 (Näyhä, 2005).

2.3.2 Temperature-associated morbidity

The scientific evidence on temperature-associated mortality suggests that non-optimum temperatures could also pose a risk for morbidity. Morbidity is feeling symptomatic or unhealthy from a disease or condition (Hernandez & Kim, 2022). Many indicators can be used to investigate temperature-associated morbidity, such as self-rated health or symptoms and physiological parameters obtained with clinical measurements (ECG, blood parameters, and so on). However, previous literature has mostly used hospital admissions as an indicator of morbidity. Existing literature on the association of non-optimum temperatures with morbidity is still scarce, demanding further research. In previous literature, a time-series study design was often used to investigate the short-term effects of temperature on morbidity. Daily morbidity counts or rates were used as outcome indicators. For exposure indicators, temperature measurements at corresponding intervals were employed (Kovats et al., 2004; Linares & Díaz, 2008; Michelozzi et al., 2009).

2.3.2.1 Heat-related morbidity

Exposure to high temperatures pose a risk for morbidity. For example, a study by Michelozzi et al. on temperature-associated morbidity in 12 European cities found that exposure to high temperatures can increase the risk of respiratory hospitalizations (Michelozzi et al., 2009). Likewise, another study from United States reported a positive association of respiratory hospitalizations with heatwaves (Gronlund et al., 2014). The changing climate and weather conditions could increase the risk of viral respiratory infections (He et al., 2023), which could explain a part of temperature associated respiratory morbidity. Additionally, existing studies on heat exposure and cardiovascular hospital admissions reported mixed results. For example, some studies have shown the association of hot days with cardiovascular admissions (Åström et al., 2011; Bhaskaran et al., 2009; Ye et al., 2012) . However, a meta-analysis by Turner et al. did not report any such association (Turner et al., 2012). The discrepancy in results could be because of geographical variations, social factors influence, the use of different morbidity measures, and methodological differences. Therefore, further multi-country studies are needed to understand the effects of temperature on human health. Studies have shown that there is an association between heat and health, and heat is predicted to increase in the future, so most probably, the effects of heat on health will also increase in the future (Kingsley et al., 2016; Lavigne et al., 2014; Peng et al., 2011; Wilk et al., 2020).

2.3.2.2 Cold-related morbidity

Existing epidemiological research has mostly focused on association of cold temperature with mortality (Conlon et al., 2011; Song et al., 2017). However, low ambient temperatures can have a profound effect on morbidity as well. For example, a study from Finland found that extremely low temperatures can increase the incidence of frostbite which could result in hospitalizations (Juopperi et al., 2002). However, there have also been reports of temperature-associated cardiorespiratory symptoms in Finland. These reports indicate aggravated symptoms and could also predict morbidity and mortality (Ikäheimo et al., 2020; Näyhä et al., 2017). The existing literature on cold-associated morbidity has shown inconsistent results. For example, a Spanish study reported an association of low temperature with cardiovascular morbidity (Rica Martínez-Solanas & Basagañaid, 2019). Contrariwise, a meta-analysis did not report any clear association of cold exposure with cardiovascular morbidity (Bunker et al., 2016). The cold-associated morbidity can also vary among specific sub-types of diseases. A systematic review revealed that 8 out of 12 studies documented an elevated risk of myocardial infarction in relation to cold temperatures (Bhaskaran et al., 2009). The existing evidence also reported inconsistency in cold-associated respiratory morbidity. In a systematic review, an increased risk for respiratory and pneumonia morbidity on exposure to low temperature was reported (Bunker et al., 2016). However, a study from Denmark reported an increased risk only among people above 80 years of age (Wichmann et al., 2012). The limited scientific evidence suggests that there is a need for additional research to further understand the morbidity effects of low winter temperatures in different geographical locations.

2.4 Physiological effects of high and low temperatures

2.4.1 Effect mechanisms of heat

Human body maintains a normal body temperature of 37 °Celsius by a process known as thermoregulation. When exposed to heat, mechanisms such as vasodilation and sweating come into play to regulate body temperature and prevent overheating. The blood vessels near the skin's surface dilate, allowing more blood to flow near the skin. This helps dissipate heat into the environment. Additionally, human body produces sweat, which evaporates from the skin's surface, carrying heat away from the body (Kurz, 2008). However, these mechanisms can also pose risks to cardiovascular health, potentially leading to hospitalizations. The vasodilation of skin blood vessels helps to transfer the heat to the environment, yet the increased cardiovascular strain resulting from this mechanism may cause possible cardiovascular events leading to hospitalizations. Similarly, sweating facilitates heat removal, but insufficient fluid intake can lead to dehydration, decrease in blood volume and electrolyte imbalance, and may cause worsening of cardiovascular strain. Consequently, the cardiovascular strain may increase the risk of cardiovascular events, leading to hospital admissions. (Lee et al., 2022).

When the physiological mechanism of sweating becomes insufficient in dissipating heat from the body, particularly in circumstances of prolonged heat exposure or inadequate hydration, the core body temperature increases more pronouncedly, and hyperthermia (core temperature >40 ^{o}C) occurs. Consequently, protein starts to denature at high temperatures, leading to tissue necroses and organ failure (Lee et al., 2022). Extreme heat in the body can severely disturb almost every organ. The stress on the cardiovascular system may lead to heart failure, especially in elderly people with preexisting cardiac disease. There could also be other complications, such as acute respiratory distress syndrome, pulmonary edema, muscle breakdown, acute renal failure, and liver failure (Morris Beker, 2018).

2.4.2 Effect mechanisms of cold

Cold exposure poses significant challenges to human thermoregulation, the mechanism maintaining normal body temperature. The initial adaptive response to cold exposure is vasoconstriction which minimizes heat dissipation from the skin to the external environment. By constricting peripheral blood vessels, vasoconstriction reduces blood flow to the skin's surface, thereby preserving core body temperature (Veicsteinas et al., 1982). This mechanism is energetically favourable and rapidly activated upon exposure to cold. In cases where vasoconstriction alone fails to properly maintain body temperature, the body activates shivering as a secondary defence mechanism. Shivering initiates involuntary muscle contractions, primarily in skeletal muscles, which generate heat through metabolic processes. This heat production, exceeding three to five times the resting metabolic rate, serves to elevate core body temperature and delay the progression of hypothermia. However, the sustainability of shivering is dependent on the availability of metabolic substrates, including carbohydrates and lipids (Frank et al., 1999). Prolonged exposure to cold temperatures can reduce these substrates, affecting the body's ability to continue shivering mechanism and causes an increased deep body temperature decline. The shivering becomes maximum at 34-35°C and ceases at 31°C (Castellani et al., 2006). When deep body temperature falls below +35°C, the threshold for hypothermia is breached, necessitating the need for urgent medical intervention (Karakayalı & Özsaraç, 2024). These occurrences may be uncommon, but they highlight the importance of addressing health complications of cold exposure.

The exposure to cold weather triggers a series of physiological responses in the human body aimed at preserving thermal equilibrium, yet these mechanisms can also cause adverse health consequences, leading to hospital admissions. When the skin undergoes cooling, vasoconstriction of skin blood vessels occurs to conserve body heat, subsequently elevating blood pressure and imposing cardiovascular strain due to increased cardiac work. This strain increases the risk for cardiovascular events, necessitating medical attention. Moreover, the altered constitution of blood resulting from hemoconcentration, and increased coagulation potential may promote clot formation. This could predispose individuals to myocardial infarctions (Ikäheimo, 2018), and could further contribute to hospital admissions.

Breathing cold and dry air, common in cold environments, can induce bronchoconstriction, leading to respiratory difficulties such as coughing, mucus production, and wheezing of breath. For individuals with pre-existing respiratory conditions like asthma or chronic obstructive pulmonary disease (COPD), this exacerbation of symptoms can require hospitalization. Furthermore, exposure to cold air may change the functional properties of the respiratory tract and compromise immune function, increasing susceptibility to respiratory tract infections (D'Amato et al., 2018). People spend more time indoors during winter, which causes indoor crowding and could also increase the chances of cross-infection. Low temperatures provide suitable conditions for the survival of bacteria in droplets (Handley & Webster, 1995). Mäkinen et al. also reported that decreased temperature and humidity could lead to the onset of respiratory tract infections (Mäkinen et al., 2008). Moreover, people with preexisting mental health conditions may also get impaired perception of extreme weather conditions and face difficulties adapting. This could lead to increased mental health visits on exposure to severely low temperatures (Rocklöv et al., 2014; Zhang et al., 2016).

2.5 Temperature and self-perceived Health

With changing weather conditions, the effect of temperature on human health is now considered an essential topic for global research (Deschenes, 2014). The relationship of temperature with mortality has been studied extensively (Basu, 2009; Ye et al., 2012). However, a limited number of studies investigated the association of temperature with self-perceived health measures. Self-perceived health is a subjective health indicator that represents the discomfort of individuals in their daily life routines. It contains in-depth, subjective information about a person's health and well-being. Some tools for evaluating self-perceived health allow participants to assess different dimensions of their health, thereby increasing the measure’s sensitivity to individual perceptions of their health (Vingilis et al., 2002).

Existing scientific literature shows that self-perceived health is an effective independent indicator of a person's health, which may also provide information on diseases that physicians could easily overlook (Jylhä et al., 2006). Several studies have reported that poor self-rated health scores increase the risk of hospital admissions and healthcare utilization. For example, a study from the US found that self-rated health was a significant predictor of global morbidity onset and cause-specific morbidity onset except cancer (Latham & Peek, 2013). Another study from Chamberlain et al. reported that self-rated measures of physical functioning predict hospitalizations and emergency department visits for heart failure patients (Chamberlain et al., 2014). Likewise, results from a Spanish study showed that poor self-rated health scores were associated with increased use of hospital services among both men and women (Tamayo-Fonseca et al., 2015). Scientific evidence on the association of non-optimum temperature with self-perceived health measures is scarce. To the best of my knowledge, only one study from China evaluated the association between ambient temperature and self-rated health (Yang et al., 2022). Some previous studies have investigated the effect of high indoor temperatures on self-rated health (Li et al., 2020; Sutton-Klein et al., 2021). However, given the limited scientific evidence available, there is a need for further studies to evaluate the association of high and low temperatures with the self-perceived health of individuals.

2.6 Lag effect of temperature

Previous studies have reported that the effect of temperature takes place with a short delay, also known as the lag effect of temperature. Lag effects for temperature can vary depending on health outcomes of interest, ranging from the same day (Green et al., 2010) to one month (Lan Chang et al., 2004). Associations were observed at shorter lags during warm days and longer lags during cold seasons (Barnett et al., 2005; Hajat & Haines, 2002). Some studies reported that the effect of hot temperature had a lag period of 1-3 days (Green et al., 2010; Koken et al., 2003; Lin et al., 2009). However, studies have shown that the association of low temperatures with health usually has a long lag period of 10-25 days (Xie et al., 2012; Zhou et al., 2014).

2.7 Susceptibility factors

Certain population groups can be more sensitive to non-optimum temperatures than others, i.e., get more easily or more serious health problems after exposure. To implement effective protective measures, it is paramount to identify the population groups that are at increased risk of exposure to extreme temperatures (Lowe et al., 2011). Therefore, this section explains how non-optimal temperatures increase the morbidity risk for different population groups.

2.7.1 Age

Extreme temperatures can affect individuals from different age groups differently. Previous literature has provided evidence that the elderly population, specifically people above 65 years of age, are more susceptible to the effects of temperature-associated morbidity. A review of studies on the impact of heat in low- and middle-income countries found that older adults were more vulnerable to the effects of high temperatures (Green et al., 2019). Ye et al. reported a significant effect of elevated temperature among people above 65 years of age (Ye et al., 2012). A meta-analysis by Bunker et al. also showed that both low and high temperature is associated with increased risk of morbidity and mortality in the elderly population (Bunker et al., 2016). The thermoregulatory ability of the body degrades with increasing age. As a result, extreme temperatures can negatively impact older adults' health (Hajat et al., 2007).

Temperature-associated morbidity and mortality are problems not only in elderly ages but also in other age groups. A study from Mediterranean cities reported the young population as highly vulnerable to the effects of heat (Leone et al., 2013). Another study from the United States found increased mortality rates for people 45-54 years of age (Yip et al., 2008). Additionally, a systematic review revealed that low and high temperatures are also associated with an increased risk of morbidity and mortality in infants (children less than one year of age) (Lakhoo et al., 2022). The vulnerability of children to low and high ambient temperatures could be because of less developed body systems, higher body surface area to body mass ratio, low awareness of heat risks and of the importance of hydration, which make them more susceptible to effects of extreme temperatures. Given the scientific evidence available, it is evident that not only the elderly but people from all other age groups especially children are also vulnerable to the effects of high and low temperatures.

2.7.2 Sex

Previous scientific literature has shown that sex modifies the association of heat with morbidity and mortality. A study from Tibet found that males were more vulnerable to heat-associated morbidity than women (Bai et al., 2014). Basu et al. reported that there was no difference between men and women in California; however, in Ontario, Canada, an increased risk was reported for women (Basu & Ostro, 2008). Likewise, in Italy and Australia, women were found to be more vulnerable to extreme temperatures than men (Stafoggia et al., 2006; Vaneckova et al., 1993). A study from Spain reported that men were at higher risk than women (Cristina et al., 2006). The possible reason for differences in temperature-associated morbidity in different sexes could be because of variations in body composition, hormonal factors, and thermoregulatory mechanisms (Kaciuba-Uscilko & Grucza, 2001). Secondly, gender-related differences can also be explained by differences in social behaviours. For example, men might be mostly employed in outdoor occupations or otherwise involved in outdoor leisure activities (Kaciuba-Uscilko & Grucza, 2001). Thirdly, physiological differences could cause differential occurrence of chronic diseases between men and women (Kaciuba-Uscilko & Grucza, 2001). If these differences are not adjusted in the model, they could contribute to gender differences in temperature-related health outcomes.

2.7.3 Socioeconomic status

Socioeconomic status (SES) can significantly influence on temperature-related vulnerability among individuals. A recent review by Song et al. showed strong evidence of higher heat risks for people with low socio-economic status (Son et al., 2019). Some previous studies have shown that areas or cities with low SES (for example, low household income, education, or gross domestic product (GDP) per capita) can have higher temperature-associated morbidity or mortality. A study by Zeng et al. found high levels of temperature related cardiovascular mortality for people with no or low education (Zeng et al., 2017). In another study, Isaksen et al. (2016) found no effect modification of temperature-associated mortality with the level of education (Isaksen et al., 2016). Another study from São Paulo, Brazil, reported effect modification of mortality effects of heat and cold by socioeconomic position. They also found that at colder temperatures, health discrepancies increase between people living in wealthy areas and less developed areas (Gouveia et al., 2003). For example, the susceptibility of individuals from lower socioeconomic backgrounds to temperature-related health risks is exacerbated by their inability to afford indoor heating during winter or acquire air-conditioning systems for summer conditions. However, it should also be noted that socioeconomic indicators can be correlated with each other, and using only one indicator, such as level of education, does not specifically represent the precise socioeconomic status of individuals. Further research is needed to understand the relationship among different SES indicators and how they modify the effect of temperature-related morbidity or mortality.

2.7.4 Pregnancy

Non-optimum temperatures can also affect pregnancy outcomes in expecting mothers. World Health Organization (WHO) suggests that pregnant women are more vulnerable to the effects of extreme ambient temperatures (WHO, 2018). Previous epidemiological studies also reported that prolonged exposure to heat can cause acute heat stress in pregnant individuals and may affect foetal development (Konkel, 2019; Rylander et al., 2013). Maternal core temperature increasing >39°C (or an increase of approximately 1.5°C to 2.0°C from baseline) can lead to increased risk for the development of the foetus (Ravanelli et al., 2019). Many systematic reviews have also suggested that low and high temperatures could cause an increased risk of preterm birth, low birth weight, and stillbirth (Chersich et al., 2020; Kuehn & McCormick, 2017). However, the studies on the association of effects of non-optimum temperatures on birth outcomes are limited and need more research.

2.7.5 Chronic diseases

People with underlying chronic disease conditions may have limited physical capacity to cope with the health consequences associated with extreme temperatures. Literature suggests that low and high temperatures may cause disease progression and mortality for people with chronic conditions such as cardiovascular, respiratory, diabetes, renal and infectious diseases (Bunker et al., 2016).

2.7.5.1 Cardiovascular diseases

Existing epidemiological evidence shows inconsistent association of non-optimum temperatures with cardiovascular disease hospitalizations. A meta-analysis and systematic review reported that high temperatures were inconsistently associated with the risk of cardiovascular hospitalizations (Phung et al., 2016). Turner et al. also suggested in a meta-analysis that the association of high temperatures with cardiovascular morbidity varies across different studies (Turner et al., 2012). However, Phung et al. found that exposure to extreme temperatures, such as heatwaves, for a more extended period significantly increases the risk of cardiovascular morbidity (Phung et al., 2016). The association of cardiovascular morbidity may vary depending on the intensity and duration of the hot period. For example, Levy et al. found that consistently high heat index causes an increase in emergency department visits (Levy et al., 2015). The association of high temperatures with cardiovascular morbidity may also vary depending on specific subtypes of cardiovascular diseases. For example, a study from Sydney, Australia, reported that vulnerability to high temperatures can be disease-specific (Vaneckova & Bambrick, 2013). They found that in specific cardiovascular subsets, ischemic heart disease (IHD) showed the most frequent admissions, while the least frequent was rheumatic fever disease. However, cardiovascular diseases as a collective group showed higher admissions only on the third day after a hot day (Vaneckova & Bambrick, 2013). Another review by Bhaskaran et al. showed that 7 out of 13 studies found an increased risk at higher temperatures for the incidence of myocardial infarction (Bhaskaran et al., 2009). An overview of the review studies did not report any such association (Song et al., 2017). The differences in results between different studies could be because of variability in demographics, geographical area, local climate, study design, and use of different methodological approaches.

Existing scientific evidence on the association of low temperature with cardiovascular morbidity is scarce and has shown varying results. For example, a study from Spain reported that cold exposure increases the risk of hospitalization for cardiovascular diseases (Rica Martínez-Solanas & Basagañaid, 2019). Contrariwise, a meta-review did not report any signs of increased risk of cardiovascular morbidity outcomes (Bunker et al., 2016). A study from Vietnam investigated the effects of cold during the year 2008-2012 on elderly cardiovascular hospital admissions. They found that cumulative cardiovascular admissions risk increases with low temperatures over 30 lag days (Giang et al., 2014). It is suggested that the real cause for concern is not the cold effect but rather the unusual decreases in temperature. As individuals have become acclimatized to consistent temperatures during specific seasons, however they may find difficult to physiologically adapt to sudden and sharp fluctuations, potentially causing body disorders (C. Liu et al., 2015).

2.7.5.2 Respiratory diseases

Existing scientific literature shows an increased vulnerability to high and low temperatures among individuals with respiratory problems. Numerous studies have reported that exposure to high ambient temperatures or heatwaves can be associated with an elevated risk for morbidity and mortality for those suffering from respiratory diseases. In a study by Michelozzi et al., high temperatures were associated with increased overall respiratory hospitalizations in 12 European countries (Michelozzi et al., 2012). Likewise, another study by Mastrenglo et al. reported that exposure to heatwaves causes an increase in respiratory hospital admissions (Mastrangelo et al., 2007). Another time series study from England found a rise in emergency hospitalization for respiratory diseases in older adults and children under five years of age (Kovats et al., 2004). Respiratory disease hospitalizations usually refer to exacerbation of asthma and COPD, as well as respiratory tract infections such as pneumonia.

Previous studies have also reported that low temperatures elevate the risk of respiratory disease morbidity. A study from China suggested that low temperatures could increase the risk of outpatient visits for all respiratory diseases in Taiwan (Y. C. Wang & Lin, 2015). Likewise, a systematic review found that cold temperatures increase the risk of total respiratory and pneumonia morbidity (Bunker et al., 2016). However, there is still limited scientific evidence available for understanding the effect of low temperatures on respiratory disease morbidity.

3 Aims of the present study

The present study was conducted to expand the scientific understanding of short-term associations of non-optimum temperatures with morbidity in general population and susceptible groups. The specific objectives of the study were the following:

1. To investigate if exposure to high daily temperatures and heatwaves increases the risk of cardiorespiratory hospital admissions and to identify susceptible population groups.

2. To estimate the effects of low daily temperatures and cold spells on cardiorespiratory hospital admissions in susceptible population groups.

3. To evaluate if exposure to non-optimum daily temperatures decreases the self-rated health of individuals.

4 Heat, Heatwaves, and Cardiorespiratory Hospital Admissions in Helsinki, Finland

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Heat, Heatwaves and Cardiorespiratory Hospital Admissions in Helsinki, Finland

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Abstract: *Background:* There is a lack of knowledge concerning the effects of ambient heat exposure on morbidity in Northern Europe. Therefore, this study aimed to evaluate the relationships of daily summertime temperature and heatwaves with cardiorespiratory hospital admissions in the Helsinki metropolitan area, Finland. *Methods*: Time series models adjusted for potential confounders, such as air pollution, were used to investigate the associations of daily temperature and heatwaves with cause-specific cardiorespiratory hospital admissions during summer months of 2001–2017. Daily number of hospitalizations was obtained from the national hospital discharge register and weather information from the Finnish Meteorological Institute. *Results*: Increased daily temperature was associated with a decreased risk of total respiratory hospital admissions and asthma. Heatwave days were associated with 20.5% (95% CI: 6.9, 35.9) increased risk of pneumonia admissions and during long or intense heatwaves also with total respiratory admissions in the oldest age group ($\geq$75 years). There were also suggestive positive associations between heatwave days and admissions due to myocardial infarction and cerebrovascular diseases. In contrast, risk of arrhythmia admissions decreased 20.8% (95% CI: 8.0, 31.8) during heatwaves. *Conclusions*: Heatwaves, rather than single hot days, are a health threat affecting morbidity even in a Northern climate.

Keywords: heat; heatwave; cardiovascular diseases; respiratory diseases; hospital admissions; climate change; ambient temperature; public health; time series; summer months

1. Introduction

Global warming is anticipated to increase the frequency and intensity of hot days and heatwaves [1]. Exposure to high temperature can lead to many types of adverse physiological changes in the human body [2,3]. Therefore, evaluating the association of ambient heat exposure with human health is of paramount importance in a changing climate.

The positive association between ambient heat exposure and mortality has been well established in countries around the world [4–8]. Results from mortality studies have been the basis for the development of heat-health warning systems and action plans [9]. However, there has been less research on the association between heat exposure and hospital admissions. This is because hospital data is typically less easily accessible than mortality data. The majority of the studies on hospital admissions have included either all-cause admissions or the broad diagnosis categories of cardiovascular and respiratory diseases.

Interestingly, studies on heat exposure and hospital admissions have exhibited mixed results [10–12]. In addition to hospital admissions due to health conditions directly related to heat stress, fluid or electrolyte imbalance, and renal diseases [13–15], respiratory admissions are commonly found to be associated with heatwaves [16–18]. Associations have also been detected with hospital admissions due to some less studied disease outcomes [19–22]. Cardiovascular diseases have shown an association with hot days in some studies [11,12,23], but no such association was found in a meta-analysis by Turner et al. [24]. Hospital admission studies have focused on extreme heat leaving the need to investigate also the effects of moderate heat [10].

Polar amplification in the northern latitudes is making Northern Europe especially susceptible to the effects of global warming [25]. So far, only few studies have been carried out to evaluate the association of high ambient temperatures with hospital admissions in Northern European countries [17,26–28]. Therefore, this study investigates the association of heat and heatwaves with cardiorespiratory hospital admissions in the Helsinki metropolitan area in Finland. Understanding how morbidity, and not just mortality, is associated with heat exposure in Northern Europe is crucial for formulating adaptation strategies.

2. Methodology

2.1. Study Design and Population

Our time series study evaluated associations between daily mean temperature and daily number of non-elective hospital admissions in the Helsinki metropolitan area, Finland, in June—August 2001–2017. The Helsinki metropolitan area includes the cities of Helsinki, Vantaa, Espoo and Kauniainen. The average population size of the area was approximately one million during the period of 2001–2017 [29].

2.2. Health and Environmental Data

Health data was obtained from a national registry containing information on daily hospital admissions. The study contained information on daily non-elective hospital admission in June–August 2001–2017 for all cardiovascular diseases (CVD: I00–I99), all respiratory diseases (J00–J99), myocardial infarction (MI: I21–I22), ischemic heart disease (IHD: I20–I25), cerebrovascular diseases (I60–I61, I63–I64), arrhythmia (I46.0, I46.9, I47–I49), asthma (J45, J46), chronic obstructive pulmonary disease (COPD: J41, J44), and pneumonia (J12–J15, J16.8, J18) in specific age groups (all ages, 18–64, 65–74 and ≥75).

Exposures of interest in the study were daily mean temperature and heatwaves. Daily weather data was provided by the Finnish Meteorological Institute. Data was collected using a fixed weather station at the Helsinki-Vantaa airport. Air pollution data was obtained from the Helsinki Region Environmental Services Authority, and included information on nitrogen dioxide (NO_2), ozone (O_3), inhalable particulate matter (PM_{10}; aerodynamic diameter $\leq$ 10 μm) and fine particulate matter ($PM_{2.5}$; aerodynamic diameter $\leq$ 2.5 μm). For NO_2, PM_{10} and $PM_{2.5}$, Kallio urban background station was used. Daily averages were calculated from 1-h values and at least 18 hourly values had to be available, otherwise daily average was defined as missing. For ozone (O_3), 8-h moving averages were calculated using hourly data from Luukki measurement site, which is an aerial background station. First, at least 6 hourly values had to be available; otherwise the 8-h moving average was defined as missing. Second, maximum daily 8-h moving averages were calculated from 8-h moving averages and at least 18 values had to be available, otherwise the maximum 8-h moving average was defined as missing. Data on daily pollen counts was provided by the University of Turku Aerobiology Unit.

2.3. Statistical Analysis

Multivariate Poisson time series regression models were used to evaluate whether daily number of hospital admissions is associated with: (1) daily mean temperature or (2) heatwaves. Previous studies have reported that the effect of high temperature on hospital admissions takes place only with a short delay. Therefore, in the analyses on the effects of daily mean temperature we looked at individual daily lags from lag 0 (exposure during the day of admission) to lag 5 (exposure 5 days prior to the day of admission). We used the average of lags 0 and 1 as the main exposure variable.

In the second set of analyses, we investigated the effect of heatwaves (extended heat exposure) by adding an indicator variable for heatwaves in the model (without daily temperature). All days belonging to heatwaves got a value of 1, all other days were 0. There is no standard definition for a heatwave, but varying combinations of intensity and duration have been used in earlier studies. In the current study, heatwaves were defined using 90th and 95th percentile cutoff points for mean daily temperature in May–August 2001–2017. For heatwaves that lasted nine days or less, the cutoff temperature had to be exceeded in each consecutive day. For heatwaves that lasted ten days or longer, one day with temperature below the cutoff point after the tenth day was allowed, if the cutoff temperature was then again exceeded for at least two consecutive days. At the 90th percentile cutoff point, heatwaves were defined as periods lasting for four or more days, and analyses were also conducted separately for short heatwaves (4–7 days) and long heatwaves (10 or more days). At the 95th cutoff point, length of heatwave was 3 or more days.

Time trends were modelled with a three-way interaction between year, month and day of the week and an indicator for holidays. Linear terms for air pollutants (NO_2, O_3, PM_{10} and $PM_{2.5}$), relative humidity (RH), and barometric pressure (BP) were introduced as potential confounders (selected a priori) in the model. Both lag 0 and the average of lags 1–3 were used for air pollutants, relative humidity, and barometric pressure. Moreover, pollen count (a sum of alder, birch, mug wort, and grasses) was taken into account using two indicators. The daily count (lag 0) and the sum of count on three previous days (lags 1–3) were categorized into two categories using 100 grains/m^3 as a cutoff.

Poisson regression was applied using the glm function in the stats package in R (R Development Core Team, Vienna, Austria) [30]. Overdispersion was checked for using the R package AER, but no evidence of that was found. Effect estimates were reported as percentage change with 95% confidence intervals. We performed analysis separately for all ages and age groups 18–64, 65–74 and ≥75 years. The shape of association of continuous exposure and covariates were checked with the gam function in the mgcv package using thin plate regression splines. This technique has advantage of not requiring the limitation of choosing the knot locations. No evidence of non-linearity was found for daily temperature; in the supplement are presented two examples of exposure-response functions (Supplemental Figures S1 and S2).

As a sensitivity analysis, we ran separate models for daily average temperature by removing days with low temperature (1st percentile, 9.4 °C) and days with high temperature (99th percentile, 24.5 °C). The models were also run without air pollutant variables to check the robustness of our results.

3. Results

Tables 1 and 2 show descriptive statistics for the outcome and exposure variables used in this study. The majority (46.3%) of all cardiorespiratory hospital admissions occurred among persons aged ≥75 years. The mean daily temperature during the study period was 16.8 °C. The average daily mean humidity was 72%. Daily mean concentrations of $PM_{2.5}$, PM_{10}, O_3 and NO_2 were 7.6, 13.2, 76.8, and 17.0 μg/m^3, respectively.

Table 1. Daily number of hospital admissions for cardiorespiratory diseases during summer months (June–August) in the Helsinki metropolitan area, Finland, 2001–2017.

Disease	**All Ages**			**Age 18–64**			**Age 65–74**			**Age ≥ 75**		
Cardiovascular	**Median**	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Median**	**Min.**	**Max.**
All	24	6	45	6	0	19	5	0	19	13	2	31
MI [1]	3	0	11	1	0	5	0	0	6	1	0	9
IHD [2]	5	0	20	1	0	8	1	0	9	2	0	12
Cerebrovascular	4	0	12	1	0	7	1	0	7	2	0	10
Arrhythmia	4	0	14	1	0	5	1	0	7	2	0	10
Respiratory												
All	16	2	37	5	0	20	3	0	12	3	0	12
Asthma	1	0	8	0	0	4	0	0	3	0	0	3
COPD [3]	2	0	9	0	0	4	1	0	6	1	0	7
Pneumonia	5	0	23	1	0	11	1	0	7	2	0	15

[1] Myocardial Infarction, [2] Ischemic Heart Disease, [3] Chronic Obstructive Pulmonary Disease.

Table 2. Daily levels of temperature, relative humidity, barometric pressure, and air pollutants during summer months (June–August) in the Helsinki metropolitan area, Finland, 2001–2017.

	Mean	**Median**	**Min.**	**Max.**	**SD.**	**Missing Values**
Meteorology						
Temperature [°C]	16.8	16.7	6.1	26.6	3.4	0
Relative Humidity [%]	72	73	37	98	12.4	0
Barometric Pressure [hPa]	1012	1012	986	1034	7.1	0
Air pollution [$\mu g/m^3$]						
Ozone	76.8	75.9	19.4	156.0	17.6	114
$PM_{2.5}$	7.6	6.6	0.5	50.2	4.6	32
PM_{10}	13.2	11.9	1.6	62.9	6.5	24
NO_2	17.0	16.0	2.9	62.6	7.5	23

Table 3 shows the number of heatwave days and mean daily temperature during heatwave and non-heatwave days.

Table 3. Number of heatwave days and mean temperature during heatwave and non-heatwave days during summer months (June–August) in the Helsinki metropolitan area, Finland, 2001–2017.

	Number of Heatwave Days	**Average Temperature During Heatwaves [°C]**	**Average Temperature During Control Days [°C]**
90th percentile			
All heatwaves	113	22.8	16.3
Short heatwaves	62	22.6	16.3
Long heatwaves	51	23.1	16.3
95th percentile			
All Heatwaves	60	23.9	16.6

Table 4 shows the associations of daily temperature, average of lags 0 and 1, with hospital admissions due to cardiorespiratory diseases. No statistically significant increased risk was found for any of the disease categories. Similar results were obtained in the analyses on individual daily lags

(Supplemental File S1–S6). There was a suggestive positive association for arrhythmia admissions in the 65–74 age group. Respiratory diseases showed a statistically significant protective association among all ages, while asthma showed a significant protective association in all ages and the 65–74 age group. All cardiovascular diseases and COPD showed borderline significant protective associations in the 18–64 and ≥75 age groups, respectively.

Table 4. Percentage change (95% CI) in daily hospital admissions for cardiorespiratory diseases associated with a 1 °C increase in daily mean temperature during summer months (June–August) in the Helsinki metropolitan area, Finland, 2001–2017.

Disease	All Ages	Age 18–64	Age 65–74	Age ≥ 75
Cardiovascular				
All	−0.49 (−1.14, 0.17)	−1.21 (−2.47, 0.07)	0.02 (−1.38, 1.44)	−0.32 (−1.22, 0.60)
MI [1]	0.14 (−1.70, 2.02)	−0.17 (−3.50, 3.28)	0.36 (−3.52, 4.39)	0.16 (−2.51, 2.90)
IHD [2]	−0.46 (−1.79, 0.88)	−0.73 (−3.22, 1.82)	−0.40 (−3.14, 2.42)	−0.37 (−2.26, 1.57)
Cerebrovascular	−0.70 (−2.22, 0.85)	−0.89 (−3.78, 2.09)	−1.37 (−4.44, 1.81)	−0.19 (−2.38, 2.06)
Arrhythmia	−0.66 (−2.24, 0.95)	−2.44 (−5.58, 0.80)	2.95 (−0.48, 6.50)	−1.52 (−3.69, 0.69)
Respiratory				
All	−1.09 (−1.88, −0.30)	0.53 (−0.90, 1.97)	−0.59 (−2.43, 1.28)	−0.11 (−1.45, 1.25)
Asthma	−3.49 (−6.25, −0.65)	3.25 (−2.11, 8.91)	−8.96 (−16.42, −0.82)	−2.68 (−8.06, 3.01)
COPD [3]	−0.53 (−2.56, 1.55)	1.54 (−2.81, 6.09)	0.97 (−2.60, 4.67)	−2.59 (−5.57, 0.49)
Pneumonia	−0.30 (−1.67, 1.09)	−0.66 (−3.17, 1.92)	−0.33 (−3.47, 2.92)	1.12 (−0.94, 3.22)

[1] Myocardial Infarction, [2] Ischemic Heart Disease, [3] Chronic Obstructive Pulmonary Disease.

Associations between heatwaves, i.e., heatwave days, and cardiorespiratory hospital admissions varied depending on the type of disease (Table 5). In the analysis where 90th percentile of the temperature distribution was used as a cutoff point, statistically significant positive associations were detected between all heatwaves and pneumonia in all ages and the 18–64 age group and all respiratory diseases in the 18–64 age group. We also found suggestive increased risk for cerebrovascular disease in all ages and COPD hospitalizations in the 18–64 age group. Protective effects were detected for arrhythmia. When short heatwaves were analyzed separately, we found significant positive associations also with COPD admissions in the 18–64 age group and MI in the 65–74 age group.

Long heatwaves (90th percentile cutoff point) and more intense heatwaves (95th percentile) showed a statistically significant increased risk for all respiratory hospitalizations in the age group ≥ 75. For hospital admissions due to pneumonia, there was a statistically significant positive association with long heatwaves and a suggestive positive association with intense heatwaves among those aged ≥ 75. We evaluated the robustness of our results by performing sensitivity analyses. Results remained essentially the same (the results are not shown).

Table 5. Percentage change (95% CI) in daily hospital admissions for cardiorespiratory diseases associated with heatwave days in summer months (June–August) in the Helsinki metropolitan area, Finland, 2001–2017.

Heatwaves	Disease	All Ages	Age 18–64	Age 65–74	Age ≥ 75
90th percentile cutoff point, all heatwaves	**Cardiovascular**				
	All	−2.14 (−7.71, 3.76)	−7.57 (−17.73, 3.84)	2.01 (−10.00, 15.62)	−0.57 (−8.30, 7.81)
	MI [1]	4.77 (−11.03, 23.38)	−6.82 (−31.64, 27.00)	40.42 (−0.43, 98.04)	−3.55 (−23.81, 22.09)
	IHD [2]	0.06 (−11.24, 12.79)	−3.50 (−23.35, 21.49)	9.62 (−14.50, 40.55)	−2.81 (−18.03, 15.23)
	Cerebrovascular	12.17 (−1.93, 28.29)	12.12 (−14.10, 46.35)	17.96 (−10.56, 55.57)	10.07 (−8.85, 32.93)
	Arrhythmia	−20.78 (−31.81, −7.97)	−34.41 (−52.71, −9.03)	−13.13 (−35.68, 17.31)	−18.44 (−33.63, 0.24)
	Respiratory				
	All	4.18 (−3.04, 11.94)	17.97 (3.97, 33.86)	−6.11 (−20.27, 10.57)	10.18 (−2.05, 23.94)
	Asthma	−4.36 (−27.46, 26.08)	17.86 (−28.57, 94.46)	−33.27 (−68.73, 42.42)	38.56 (−15.15, 126.25)
	COPD [3]	−5.03 (−20.95, 14.10)	48.05 (0.00, 119.20)	−9.48 (−33.48, 23.18)	−20.67 (−40.38, 5.55)
	Pneumonia	20.48 (6.85, 35.85)	28.94 (3.00, 61.42)	25.67 (−4.24, 64.93)	18.25 (−0.82, 40.98)
90th percentile cutoff point, short heatwaves	**Cardiovascular**				
	All	−1.32 (−8.05, 5.91)	−3.64 (−16.10, 10.68)	3.48 (−11.15, 20.53)	−1.76 (−10.92, 8.35)
	MI [1]	17.13 (−3.44, 42.07)	5.21 (−28.12, 54.01)	74.86 (15.75, 164.16)	2.36 (−21.99, 34.31)
	IHD [2]	8.47 (−5.70, 24.78)	2.63 (−22.04, 35.11)	21.29 (−9.64, 62.81)	5.47 (−13.30, 28.31)
	Cerebrovascular	12.27 (−4.19, 31.56)	19.07 (−12.40, 61.84)	4.48 (−25.99, 47.49)	12.23 (−9.94, 39.87)
	Arrhythmia	−26.85 (−39.36, −11.76)	−33.82 (−55.37, −1.87)	−10.75 (−38.04, 28.56)	−32.07 (−48.07, −11.15)
	Respiratory				
	All	5.24 (−3.58, 14.86)	27.03 (9.49, 47.38)	−3.89 (−21.44, 17.59)	−1.04 (−14.72, 14.85)
	Asthma	21.58 (−10.78, 65.68)	47.11 (−18,23, 164.64)	0.23 (−57.34, 135.48)	72.41 (−1.01, 200.29)
	COPD [3]	−6.98 (−25.78, 16.58)	65.33 (3.13, 165.06)	−10.06 (−38.48, 31.50)	−28.29 (−49.87, 2.59)
	Pneumonia	20.31 (3.49, 39.87)	48.30 (13.87, 93.15)	33.99 (−4.80, 88.59)	−0.30 (−21.09, 25.96)
90th percentile cutoff point, long heatwaves	**Cardiovascular**				
	All	−3.01 (−11.46, 6.24)	−13.56 (−28.14, 3.97)	−1.46 (−18.64, 19.35)	2.50 (−9.60, 16.23)
	MI [1]	−12.85 (−32.96, 13.31)	−18.09 (−49.11, 31.86)	−6.02 (−44.48, 59.11)	−12.16 (−40.86, 30.47)
	IHD [2]	−13.36 (−28.82, 5.47)	−11.50 (−38.68, 27.73)	−6.97 (−37.40, 38.24)	−17.85 (−38.41, 9.58)
	Cerebrovascular	7.87 (−13.15, 33.98)	−12.16 (−43.75, 37.16)	38.92 (−7.90, 109.53)	4.53 (−23.67, 43.14)
	Arrhythmia	−8.34 (−26.27, 14.57)	−29.16 (−57.62, 18.40)	−24.17 (−52.31, 20.57)	10.09 (−18.10, 47.98)
	Respiratory				
	All	−1.01 (−11.29, 10.46)	−0.85 (−18.99, 21.35)	−12.54 (−31.42, 11.54)	22.47 (3.14, 45.43)
	Asthma	−52.46 (−71.80, 19.74)	−22.69 (−67.96, 86.48)	−76.19 (−93.91, −6.86)	−25.76 (−67.86, 71.52)
	COPD [3]	−1.63 (−25.35, 29.63)	35.11 (−26.14, 147.14)	−7.93 (−42.00, 46.17)	−10.78 (−41.60, 36.30)
	Pneumonia	18.20 (−0.94, 41.03)	−0.82 (−31.20, 42.97)	11.85 (−24.42, 65.53)	40.65 (9.87, 80.05)

Table 5. *Cont.*

Heatwaves	Disease	All Ages	Age 18–64	Age 65–74	Age ≥ 75
95th percentile cutoff point, all heatwaves	**Cardiovascular**				
	All	−2.43 (−9.60, 5.31)	−12.15 (−24.15, 2.23)	−1.07 (−15.82, 16.25)	2.22(−8.07, 13.67)
	MI [1]	3.02 (−17.04, 27.93)	−13.29 (−43.04, 32.00)	9.38 (−29.32, 69.27)	8.03 (−21.07, 47.85)
	IHD [2]	1.83 (−13.03, 19.24)	−14.20 (−37.31, 17.42)	3.11 (−24.99, 41.72)	9.44 (−12.54, 36.95)
	Cerebrovascular	−3.86 (−19.65, 15.05)	−34.11 (−54.61, −4.36)	13.26 (−20.43, 61.20)	6.23 (−17.64, 37.00)
	Arrhythmia	−14.67 (−29.62, 3.45)	−13.72 (−41.67, 27.61)	−18.75 (−45.62, 21.41)	−13.82 (−34.07, 12.66)
	Respiratory				
	All	1.77 (−7.27, 11.71)	−0.37 (−15.56, 17.57)	−18.93 (−34.51, 0.36)	22.46 (5.62, 41.98)
	Asthma	11.30 (−24.55, 64.21)	27.09 (−38.56, 162.86)	−28.62 (−72.94, 88.25)	68.89 (−8.60, 212.10)
	COPD [3]	4.93 (−16.87, 32.44)	42.26 (−15.37, 139.15)	−25.69 (−50.41, 11.37)	18.38 (−16.41, 67.63)
	Pneumonia	6.80 (−8,66, 24.88)	−5.95 (−30.44, 27.17)	3.51 (−27.49, 47.76)	24.16 (−0.64, 55.15)

[1] Myocardial Infarction, [2] Ischemic Heart Disease, [3] Chronic Obstructive Pulmonary Disease.

4. Discussion

This study investigated separately the associations of daily mean temperature and heatwaves with hospital admissions for cardiorespiratory diseases in summer months (June–August) in the Helsinki metropolitan area, Finland. We found that daily mean temperature was associated with a decreased risk of hospitalization for all respiratory diseases, asthma, and to a lesser extent cardiovascular diseases. In contrast, during heatwaves the risk of hospitalization increased due to pneumonia, and in some age groups for respiratory diseases in general, COPD and MI. We also found a negative association between heatwaves and arrhythmia hospitalizations.

Our study results showed no increased risk for all cardiovascular admissions in association with daily mean temperature or heatwaves. These findings are in line with a review, in which Turner et al. found no association between summertime temperature and cardiovascular morbidity [24]. Likewise, many later studies have shown either no or weak association between heat and cardiovascular morbidity [16,31–33]. One potential reason could be that most of the vulnerable people suffering acute cardiovascular events die before reaching hospital, which may explain the lack of effect on cardiovascular hospital admissions [17].

Our results suggest that heatwaves may yet be associated with specific subtypes of cardiovascular diseases. We found a borderline significant association between heatwave days and cerebrovascular admissions among all ages. However, there has been no evidence in previous literature for an effect of heat or heatwaves on cerebrovascular admissions, and no association with cerebrovascular morbidity was found in an overview of review studies [34]. Our study also indicates a positive association between heatwaves and myocardial infarction admissions in the 65–74 age group, which is in contrast with previous studies that found no or a decreased risk of MI admissions during summer months [27,35,36].

We also observed a protective association between heatwaves and hospital admissions due to arrhythmia. In contrast, a population based study from Canada did not find any association between heat and arrhythmia admissions [37]. So far, there are too few studies to draw conclusions on the effect on arrhythmia.

We found a positive association of heatwaves with hospital admissions due to respiratory diseases in general, pneumonia and COPD. These results are consistent with the findings from previous studies on respiratory morbidity [16–18,38,39]. A possible explanation for a stronger association between heatwaves and respiratory admissions than between heatwaves and cardiovascular admissions is that respiratory diseases are not as acutely fatal as cardiovascular diseases. This means that more people are able to reach hospitals. During heat exposure human body maintains safe body temperature through thermoregulation, which results in an increase in skin blood flow, cardiac output, and pulmonary ventilation [40–42]. Hyperthermia can also lead to thermal hyperpnea (increase in respiratory rate and tidal volume) [40]. These responses can lead to exacerbation of respiratory diseases and an increase in hospitalizations. Moreover, it has been suggested that acute respiratory effects can be caused by the direct effect of breathing hot air [18].

In our study, long heatwaves and more intense heatwaves (95th percentile cutoff point) were associated with an increased risk of total respiratory and pneumonia hospitalizations in the oldest age category. These findings are in line with other studies, which have reported elderly people as the most vulnerable group for respiratory morbidity effects due to high daily temperatures and heatwaves [17,31,43,44]. However, with different definitions of heatwaves we also found associations between heatwaves and respiratory health in the age group 18–64.

The risk of morbidity associated with heatwaves may vary depending on the length and intensity of the hot period. In a study by Levy et al., sustained high heat index increased the risk of emergency department arrivals [45]. Likewise, a study in Australia found a higher risk of infants' hospitalizations with longer duration heatwaves [46]. The effect of heatwaves on morbidity may vary across different regions and still needs more investigation.

Finland, being a North European country, has cool summer temperatures. This is most likely the reason that we found no positive associations or even some protective associations in connection with daily temperature. However, our results do suggest that heatwaves pose a public health concern regarding morbidity (as indicated by hospital admissions).

One of the strengths of our study is that it was conducted in a Northern climate where only few studies have taken place. We used long time series data and had in practice a hundred percent coverage of hospital admissions. Thus, reliable evidence on population level associations could be provided. Also, this study evaluated the associations of temperature with cause-specific diagnosis and in age groups rather than for broader disease categories and total population. The potential confounding effect of air pollution was controlled using all major indicators of air pollution. However, this study has some limitations as well. We were not able to include persons younger than 18 years because the limited number of cases in the age group would have led to imprecise effect estimates. Further, the number of events was low also in some age-stratified analyses on sub-diagnoses, e.g., on asthma, which has to be taken into account when interpreting the results. Finally, the study only included cardiovascular and respiratory hospital admissions. Admissions due to other causes could also be affected by heat exposure.

5. Conclusions

In conclusion, we found no associations and even protective associations between daily mean temperature and cardiorespiratory hospital admissions. However, our results do suggest that heatwaves are a health threat and affect morbidity even in the northern climate. Moreover, it is not only the elderly who are at risk. Preventive measures should also take other age groups into account.

Supplementary Materials: The following are available online at http://www.mdpi.com/1660-4601/17/21/7892/s1, Figure S1: Shape of association between daily mean temperature and cardiovascular hospital admissions during summer months in Helsinki metropolitan area, Finland, 2001–2017, Figure S2: Shape of association between daily mean temperature and respiratory admissions during summer months in Helsinki, metropolitan area, Finland, 2001–2017, File S1: Lag 0; File S2: Lag 1; File S3: Lag 2; File S4: Lag 3; File S5: Lag 4; File S6: Lag 5.

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Supplementary material:

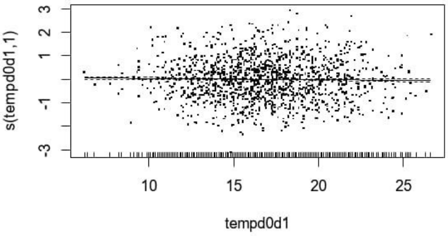

Figure S1. Shape of association between daily mean temperature and cardiovascular hospital admissions during summer months in Helsinki metropolitan area, Finland, 2001–2017.

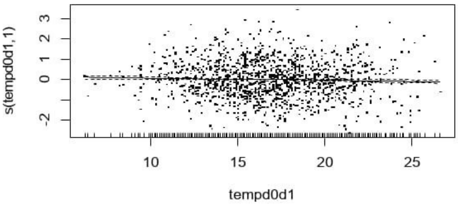

Figure S2. Shape of association between daily mean temperature and respiratory admissions during summer months in Helsinki metropolitan area, Finland, 2001–2017.

File S1: Lag 0

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with a 1 °C increase in daily mean temperature during summer months in the Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change RR	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.52	−0.95	−0.08	0.02
Respiratory	−1.47	−1.97	−0.98	0.00
MI	−0.35	−1.59	0.91	0.59
IHD	−0.37	−1.29	0.55	0.42
Cerebrovascular	−0.22	−1.25	0.82	0.68
Arrhythmia	−1.33	−2.37	−0.28	0.01
Asthma	−2.66	−4.39	−0.89	0.00
COPD	−0.04	−1.40	1.33	0.95
Pneumonia	−0.98	−1.84	−0.12	0.03

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change RR	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−1.03	−1.88	−0.17	0.02
Respiratory	−0.78	−1.70	0.16	0.10
MI	−0.66	−2.89	1.62	0.57
IHD	−0.52	−2.23	1.21	0.55
Cerebrovascular	−0.51	−2.50	1.53	0.62
Arrhythmia	−1.55	−3.65	0.59	0.15
Asthma	−1.02	−4.32	2.39	0.55
COPD	1.59	−1.29	4.56	0.28
Pneumonia	−1.39	−3.01	0.25	0.10

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change RR	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.25	−1.19	0.69	0.60
Respiratory	−0.84	−2.02	0.36	0.17
MI	−0.56	−3.16	2.11	0.68
IHD	−0.33	−2.21	1.58	0.73
Cerebrovascular	0.32	−1.73	2.40	0.76
Arrhythmia	0.79	−1.45	3.08	0.49
Asthma	−3.83	−8.87	1.49	0.15
COPD	−0.71	−3.01	1.64	0.55
Pneumonia	−1.57	−3.52	0.43	0.12

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change RR	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.39	−1.07	0.22	0.21
Respiratory	−0.66	−1.72	0.21	0.13
MI	−0.02	−0.97	1.83	0.98
IHD	−0.29	−1.25	1.04	0.66
Cerebrovascular	−0.34	−1.41	1.16	0.66
Arrhythmia	−2.28	−5.12	−0.83	0.00
Asthma	−1.50	−4.67	2.06	0.40
COPD	−0.32	−1.68	1.78	0.76
Pneumonia	0.08	−0.51	1.40	0.91

File S2: Lag 1

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.31	−0.69	0.07	0.11
Respiratory	−0.85	−1.28	−0.41	0.00
MI	0.04	−1.05	1.14	0.95
IHD	0.00	−0.80	0.81	1.00
Cerebrovascular	−0.34	−1.23	0.57	0.46
Arrhythmia	−0.58	−1.49	0.34	0.22
Asthma	−1.95	−3.49	−0.38	0.01
COPD	0.42	−0.76	1.61	0.49
Pneumonia	−0.41	−1.16	0.35	0.29

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.40	−1.14	0.36	0.30
Respiratory	−0.34	−1.15	0.48	0.42
MI	−0.62	−2.56	1.36	0.54
IHD	−0.42	−1.91	1.10	0.59
Cerebrovascular	0.36	−1.39	2.13	0.69
Arrhythmia	−0.91	−2.76	0.97	0.34
Asthma	0.62	−2.31	3.63	0.68
COPD	2.18	−0.36	4.78	0.09
Pneumonia	−1.54	−2.96	−0.11	0.04

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.17	−0.99	0.65	0.68
Respiratory	−0.19	−1.23	0.85	0.72
MI	0.84	−1.44	3.18	0.47
IHD	0.32	−1.32	2.00	0.70
Cerebrovascular	−0.51	−2.28	1.30	0.58
Arrhythmia	0.91	−1.04	2.89	0.36
Asthma	−4.07	−8.48	0.55	0.08
COPD	0.46	−1.57	2.53	0.66
Pneumonia	−0.94	−2.66	0.81	0.29

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.34	−0.86	0.20	0.22
Respiratory	−0.18	−0.92	0.58	0.65
MI	0.11	−1.49	1.74	0.89
IHD	0.09	−1.06	1.25	0.88
Cerebrovascular	−0.56	−1.84	0.74	0.40
Arrhythmia	−1.13	−2.39	0.14	0.08
Asthma	−1.67	−4.71	1.46	0.29
COPD	−0.50	−2.26	1.30	0.58
Pneumonia	0.70	−0.44	1.84	0.23

File S3: Lag 2

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.47	−0.81	−0.12	0.01
Respiratory	−0.63	−1.03	−0.23	0.00
MI	−0.27	−1.27	0.74	0.59
IHD	−0.35	−1.08	0.38	0.35
Cerebrovascular	−0.49	−1.30	0.33	0.24
Arrhythmia	−0.81	−1.65	0.03	0.06
Asthma	−1.08	−2.51	0.37	0.14
COPD	0.29	−0.80	1.38	0.60
Pneumonia	0.00	−0.69	0.70	0.99

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.66	−1.33	0.03	0.06
Respiratory	−0.17	−0.92	0.58	0.65
MI	−1.14	−2.91	0.65	0.21
IHD	−0.87	−2.22	0.50	0.21
Cerebrovascular	0.11	−1.46	1.70	0.90
Arrhythmia	−0.96	−2.66	0.77	0.27
Asthma	1.41	−1.25	4.15	0.30
COPD	1.39	−0.88	3.71	0.23
Pneumonia	−0.58	−1.91	0.76	0.39

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1°C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.04	−0.79	0.72	0.92
Respiratory	−0.17	−1.12	0.79	0.73
MI	0.51	−1.60	2.67	0.64
IHD	0.02	−1.48	1.54	0.98
Cerebrovascular	−0.26	−1.89	1.40	0.75
Arrhythmia	0.44	−1.35	2.27	0.63
Asthma	−1.38	−5.46	2.88	0.52
COPD	0.38	−1.48	2.28	0.69
Pneumonia	−0.65	−2.25	0.97	0.43

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.56	−1.04	−0.07	0.02
Respiratory	0.08	−0.60	0.77	0.82
MI	−0.08	−1.55	1.42	0.92
IHD	−0.23	−1.28	0.84	0.67
Cerebrovascular	−0.92	−2.10	0.27	0.13
Arrhythmia	−1.35	−2.49	−0.19	0.02
Asthma	−0.93	−3.75	1.98	0.53
COPD	−0.44	−2.08	1.23	0.61
Pneumonia	0.78	−0.24	1.82	0.13

File S4: Lag 3

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.47	−0.81	−0.12	0.01
Respiratory	−0.63	−1.03	−0.23	0.00
MI	−0.27	−1.27	0.74	0.59
IHD	−0.35	−1.08	0.38	0.35
Cerebrovascular	−0.48	−1.25	0.30	0.23
Arrhythmia	−0.58	−1.37	0.21	0.15
Asthma	−1.60	−2.96	−0.22	0.02
COPD	0.41	−0.62	1.45	0.43
Pneumonia	−0.12	−0.78	0.54	0.72

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.66	−1.33	0.03	0.06
Respiratory	−0.17	−0.92	0.58	0.65
MI	−1.14	−2.91	0.65	0.21
IHD	−0.87	−2.22	0.50	0.21
Cerebrovascular	−0.03	−1.51	1.47	0.97
Arrhythmia	−0.84	−2.46	0.80	0.31
Asthma	0.55	−1.99	3.15	0.67
COPD	1.18	−0.99	3.40	0.29
Pneumonia	−0.54	−1.80	0.73	0.40

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1°C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.04	−0.79	0.72	0.92
Respiratory	−0.17	−1.12	0.79	0.73
MI	0.51	−1.60	2.67	0.64
IHD	0.02	−1.48	1.54	0.98
Cerebrovascular	−0.29	−1.84	1.29	0.72
Arrhythmia	0.14	−1.56	1.86	0.88
Asthma	−3.86	−7.57	0.01	0.05
COPD	0.40	−1.35	2.19	0.65
Pneumonia	−0.34	−1.86	1.20	0.66

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.56	−1.04	−0.07	0.02
Respiratory	0.08	−0.60	0.77	0.82
MI	−0.08	−1.55	1.42	0.92
IHD	−0.23	−1.28	0.84	0.67
Cerebrovascular	−0.83	−1.95	0.30	0.15
Arrhythmia	−0.85	−1.93	0.24	0.13
Asthma	−1.72	−4.41	1.04	0.22
COPD	−0.05	−1.61	1.54	0.95
Pneumonia	0.43	−0.55	1.41	0.39

File S5: Lag 4

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.39	−0.72	−0.07	0.02
Respiratory	−0.46	−0.83	−0.09	0.01
MI	−0.49	−1.41	0.45	0.30
IHD	−0.71	−1.38	−0.03	0.04
Cerebrovascular	−0.60	−1.35	0.16	0.12
Arrhythmia	−0.84	−1.60	−0.06	0.03
Asthma	−1.28	−2.63	0.09	0.07
COPD	0.49	−0.51	1.50	0.34
Pneumonia	−0.38	−1.02	0.26	0.24

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.24	−0.87	0.40	0.46
Respiratory	−0.03	−0.73	0.67	0.93
MI	−0.86	−2.50	0.80	0.31
IHD	−1.09	−2.34	0.17	0.09
Cerebrovascular	0.23	−1.23	1.70	0.76
Arrhythmia	−0.40	−1.97	1.20	0.62
Asthma	0.74	−1.78	3.31	0.57
COPD	1.39	−0.73	3.56	0.20
Pneumonia	−0.92	−2.14	0.31	0.14

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.25	−0.94	0.44	0.48
Respiratory	−0.24	−1.12	0.65	0.60
MI	−0.23	−2.22	1.79	0.82
IHD	−0.19	−1.59	1.23	0.79
Cerebrovascular	0.04	−1.46	1.57	0.96
Arrhythmia	−0.16	−1.81	1.53	0.86
Asthma	−1.48	−5.19	2.37	0.45
COPD	−0.05	−1.76	1.69	0.95
Pneumonia	−0.27	−1.75	1.23	0.72

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.55	−1.00	−0.11	0.02
Respiratory	0.04	−0.59	0.67	0.91
MI	−0.36	−1.72	1.01	0.60
IHD	−0.72	−1.70	0.26	0.15
Cerebrovascular	−1.38	−2.45	−0.30	0.01
Arrhythmia	−1.45	−2.50	−0.39	0.01
Asthma	−1.73	−4.39	1.00	0.21
COPD	0.39	−1.13	1.94	0.61
Pneumonia	0.11	−0.83	1.05	0.82

File S6: Lag 5

Table 1. Percentage change in daily hospital admissions for cardiorespiratory diseases (All-ages) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.39	−0.70	−0.07	0.02
Respiratory	−0.61	−0.97	−0.24	0.00
MI	−0.68	−1.59	0.23	0.14
IHD	−1.09	−1.75	−0.42	0.00
Cerebrovascular	−0.13	−0.86	0.61	0.73
Arrhythmia	−0.77	−1.53	−0.01	0.05
Asthma	−1.81	−3.14	−0.46	0.01
COPD	0.44	−0.55	1.44	0.38
Pneumonia	−0.50	−1.13	0.13	0.12

Table 2. Percentage change in daily hospital admissions for cardiorespiratory diseases (18–64 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.30	−0.92	0.33	0.35
Respiratory	−0.42	−1.10	0.27	0.23
MI	−1.04	−2.67	0.61	0.22
IHD	−1.44	−2.67	−0.19	0.02
Cerebrovascular	0.51	−0.92	1.97	0.49
Arrhythmia	−0.89	−2.46	0.70	0.27
Asthma	−0.54	−3.00	1.99	0.67
COPD	1.27	−0.79	3.37	0.23
Pneumonia	−1.17	−2.37	0.04	0.06

Table 3. Percentage change in daily hospital admissions for cardiorespiratory diseases (65–74 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.01	−0.69	0.67	0.97
Respiratory	−0.03	−0.90	0.85	0.95
MI	−0.61	−2.52	1.33	0.54
IHD	−0.41	−1.78	0.98	0.56
Cerebrovascular	0.54	−0.94	2.05	0.47
Arrhythmia	0.31	−1.31	1.95	0.71
Asthma	−0.95	−4.64	2.89	0.62
COPD	0.11	−1.57	1.82	0.90
Pneumonia	−0.58	−2.04	0.90	0.44

Table 4. Percentage change in daily hospital admissions for cardiorespiratory diseases (≥75 years age group) associated with 1 °C increase in daily mean temperature during summer months in Helsinki metropolitan area, Finland, 2001–2017.

Outcome	% change	Low CI (%)	Up CI(%)	*p*-value
Cardiovascular	−0.60	−1.04	−0.16	0.01
Respiratory	0.00	−0.62	0.62	1.00
MI	−0.53	−1.85	0.81	0.44
IHD	−1.20	−2.16	−0.24	0.01
Cerebrovascular	−0.81	−1.86	0.25	0.13
Arrhythmia	−1.26	−2.29	−0.22	0.02
Asthma	−1.92	−4.52	0.75	0.16
COPD	0.21	−1.30	1.74	0.79
Pneumonia	0.15	−0.77	1.08	0.75

5 Low temperature, cold spells, and cardiorespiratory hospital admissions in Helsinki, Finland

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Low temperature, cold spells, and cardiorespiratory hospital admissions in Helsinki, Finland

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Abstract

There is only limited scientific evidence with varying results on the association between hospital admissions and low ambient temperatures. Furthermore, there has been no research in Northern Europe on cold-associated morbidity. Therefore, this study investigated the associations of daily wintertime temperature and cold spells with cardiorespiratory hospital admissions in the Helsinki metropolitan area, Finland. Daily number of non-elective hospital admissions for 2001–2017 was obtained from the national hospital discharge register and meteorological data from the Finnish Meteorological Institute. Quasi-Poisson regression models were fitted, controlling for potential confounders such as time trend, weekday, holidays, air pollution, barometric pressure, and influenza. The associations of cold season daily mean ambient temperature and cold spells with hospital admissions were estimated using a penalized distributed lag linear models with 21 lag days. Decreased wintertime ambient temperature was associated with an increased risk of hospitalization for myocardial infarction in the whole population (relative risk [RR] per 1 °C decrease in temperature: 1.017, 95% confidence interval [CI]: 1.002–1.032). An increased risk of hospital admission for respiratory diseases (RR: 1.012, 95% CI: 1.002, 1.022) and chronic obstructive pulmonary disease (RR: 1.031, 95% CI: 1.006, 1.056) was observed only in the ≥ 75 years age group. There was an independent effect of cold spell days only for asthma admissions (RR: 2.348, 95% CI: 1.026, 5.372) in the all-ages group. Cold temperature increases the need for acute hospital care due to myocardial infarction and respiratory causes during winter in a northern climate.

Keywords Temperature · Cold temperature · Weather · Morbidity · Epidemiology

Introduction

Extremes in weather, including air temperature, can have a profound effect on human health. Both low and high temperatures are associated with morbidity and mortality worldwide (Basu and Samet 2002; Ye et al. 2012). The Intergovernmental Panel on Climate Change projects that though the global mean temperature is increasing globally,

Highlights

- Low temperatures during cold days are a serious public health concern in northern climate.
- Individual cold days increase the need for acute hospital care due to myocardial infarction and respiratory causes.
- Cold spells (10th percentile cutoff point) presented an increased risk for COPD admissions.
- No evidence of an added effect of cold spells was found, except for asthma.

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occasional cold winter extremes will continue to occur in the future (Collins et al. 2013). At the same time, adaptation to warmer climates may turn populations more susceptible to cold extremes (Arbuthnott et al. 2016). Hence, low temperatures will remain a public health threat in susceptible geographic areas. Therefore, it is essential to understand better the association of low temperatures with human health.

Most of the epidemiological research on low temperatures has focused on the mortality effects (Conlon et al. 2011; Song et al. 2017). Scientific evidence on the effects of cold exposure on cardiovascular morbidity is limited and results have been varying. A recent study from Spain found an increased risk of hospitalizations for cardiovascular diseases with cold exposure (Martinez-Solanas and Basagana 2019). However, a meta-analysis reported no clear effects of cold exposure on the risk of cardiovascular or cerebrovascular morbidity (Bunker et al. 2016). Concerning myocardial infarction risk in association with cold, a systematic review reported that 8 out of 12 studies reported an increased risk (Bhaskaran et al. 2009).

Results on the association of cold exposure with respiratory admissions are also scarce and inconsistent. A systematic review found an increased risk for cold-induced respiratory and pneumonia morbidity (Bunker et al. 2016). In a study conducted in Denmark, Wichmann et al. (2011) found an association between low temperature and respiratory admissions only in people above 80 years of age (Wichmann et al. 2011). All in all, given the limited scientific evidence available, there is a need for further research to understand better the effect of low wintertime temperatures on cardiorespiratory morbidity.

Studies on association of cold spells with cardiorespiratory hospital admissions are limited. These studies have reported an increased risk of morbidity during cold spell days in comparison to non-cold spell days. For example, a study from Lithuania found increased risk for acute myocardial infarction during cold spell days (Vaičiulis et al. 2011). Likewise, another study found increased risk of asthma admissions during cold spells in China (Chen et al. 2021). However, to our knowledge, no studies have investigated the association of cold spells with cardiorespiratory hospital admissions in Northern Europe.

Even though ambient temperatures will increase worldwide, the climate in Northern Europe will generally stay cold. Exposure–response functions may vary between more and less cold climatic regions. Studies have reported that most of the temperature-related deaths in Northern European countries, like Sweden and Finland, are due to cold temperatures (Åström et al. 2018; Ruuhela et al. 2018). However, limited knowledge exists on the association of cold temperatures with morbidity in Northern Europe. Thus, the main aim of this study is to investigate the associations of low temperatures and cold spells with cause-specific morbidity in the Helsinki metropolitan area, Finland. Finland is a Nordic country with extremely low wintertime temperatures. Additionally, this study also evaluated difference in the relationship for the older age group (≥ 75 years).

Methodology

Study population and setting

This study investigated the associations of low temperatures and cold spells with cardiorespiratory hospital admissions in the Helsinki metropolitan area, during cold season (October–March), 2001–2017. The Helsinki metropolitan area includes the cities of Helsinki, Vantaa, Espoo, and Kauniainen and has a population size of approximately one million (2001–2017) Key Figures on Population by Area, Information and Year-Tilastokeskuksen Px-Web Tietokannat (n.d.).

Data source

We obtained health data from a national health register having information on daily hospital admissions. Data was coded according to the International Classification of Diseases 10th Revision (World Health Organization 2015). The obtained data contained daily non-elective hospital admissions for all cardiovascular diseases (CVD; ICD-10 codes: I00–I99), all respiratory diseases (J00–J99), myocardial infarction (MI; I21–I22), ischemic heart disease (IHD; I20–I25), cerebrovascular diseases (I60–I61, I63–I64), arrhythmia (I46.0, I46.9, I47–I49), asthma (J45, J46), chronic obstructive pulmonary disease (COPD; J41, J44), and pneumonia (J12–J15, J16.8, J18) for all ages, and stratified by age groups (18–64, 65–74, and ≥ 75). The daily number of cases was low in all age groups except for ≥ 75 years; thus, the focus was on this age group.

Key exposure variables in the study were daily mean temperature and cold spells. There is no standard definition for cold spells, but different combinations of intensity and length have been used previously. In this study, we defined cold spells as periods during which daily mean temperature was lower than 10th or 5th percentile of the temperature distribution (during October–March 2001–2017) for four consecutive days or longer. All the days within a cold spell got the value 1, all other days 0. We obtained the meteorological data from the Finnish Meteorological Institute; a fixed weather station at the Helsinki-Vantaa airport was used to collect the data. Data on nitrogen dioxide (NO_2), ozone (O_3), inhalable particulate matter (PM_{10}; aerodynamic diameter ≤ 10 μm), and fine particulate matter ($PM_{2.5}$; aerodynamic diameter ≤ 2.5 μm) was obtained from the Helsinki Region Environmental Services Authority.

We calculated daily averages of NO_2, PM_{10}, and $PM_{2.5}$ from hourly data of Kallio urban background station. If there were less than 18 hourly values available per day, the daily average was defined as missing. Information on ozone (O_3) was collected by calculating an 8-h moving average from hourly data of the Luukki measurement site (areal background station). For daily pollen count, the University of Turku, Aerobiology Unit, provided the data.

Statistical analyses

We used a quasi-Poisson regression because this type of hospital admissions data is known to lead to problems with overdispersion in data analyses. Distributed lag non-linear models (DLNM) were used to investigate the lagged (delayed) and cumulative lagged effects of (a) daily mean temperature and (b) cold spells on the daily number of hospital admissions in colder months. The DLNM modeling framework can simultaneously depict delayed effects (lags) and non-linear exposure–response dependencies. Based on the definition of a "cross-basis," a bidimensional space of functions that simultaneously describes the shape of the relationship along the predictor space and lag dimension of its occurrence; this methodology explains the relationship along both dimensions. It is possible to visualize cross-basis as a bi-dimensional space of functions that simultaneously describe the pattern of the relationship along predictor x and its distributed lag effects. The process of selecting a cross-basis entails selecting two sets of basis functions that will be merged to produce the cross-basis functions (Gasparrini et al. 2010).

In the first stage of the analyses, DLNM models with temperature lags up to 21 days were used to investigate the cumulative association of daily mean temperature with hospitalizations. Longer lag period was selected to capture the delayed overall effect of cold exposure, which is line with previous literature (Xie et al. 2013; Zhou et al. 2014). However, we also tested alternative lag periods in the sensitivity analyses. In cross-basis matrix, temperature effect was treated as linear because shape of association was approximately linear between temperature and outcomes. Lagged effects were calculated with penalized thing regression splines having an upper limit of 9 degrees of freedom (df) for basis function. The upper limit of degrees of freedom as well as penalization of spline functions was set to avoid unrealistically detailed lag structure.

In the second stage of the analyses, we investigated the effect of cold spells. The analysis was conducted by separately adding a cross-basis term for cold spells in the DLNM models. Finally, we introduced daily temperature and cold spells together in the same model to estimate the possible added effect of prolonged cold, i.e., whether during cold spells the effect of low temperatures was stronger than during isolated days of cold.

All models were adjusted for potential confounders, i.e., variables that may correlate with both exposure and outcome in time. Time and seasonal trends were controlled using natural cubic splines with six degrees of freedom (*df*) per year, and indicator terms for the day of the week and holidays. Influenza, air pollutants (NO_2, O_3, PM_{10}, and $PM_{2.5}$), relative humidity (RH), and barometric pressure (BP) were introduced as potential confounders (selected a priori) in the models. Influenza was defined as a categorical covariate with three categories: 0–49, 50–149, or 150 + diagnosed influenza cases per week in the study area (week refers to all days of that week). We used 2-day averages (lags 0–1) for air pollutants, relative humidity, and barometric pressure. Thin plate regression splines in the mgcv package were used to check the shape of association for the continuous covariates (Wood 2006). Moreover, models were adjusted for pollen count (a sum of alder, birch, mug wort, and grasses) using an indicator showing the sum of the counts on two days (lags 0 and 1), categorized dichotomously using 100grains/m^3 as a cutoff.

For the analyses, we used R studio for statistical computing (version: 3.6.0) with the "mgcv" and "dlnm" packages (Gasparrini et al. 2010; Wood 2006). Effect estimates were reported as risk ratios with 95% confidence intervals. We performed analyses separately for the all-ages and ≥ 75 years age groups.

Sensitivity analyses

In the sensitivity analyses, we changed the lag periods for daily mean temperature. The models were run using both relatively short (14 days) and long (28-day) lag periods. Moreover, we used windchill (the degree of the cold as perceived by the human body, which gets worse by high wind speed) as an exposure indicator to check if it is a better predictor of cold effects than temperature alone. Wind chill was defined using the formula from Osczevski et al. (Osczevski and Bluestein 2005) and modified for Finland's weather conditions by the Finnish Meteorological Institute as follows:

$$\text{Wind chill} = 15 + 22/37 * \mathrm{T} + 15/37 * ((V + 1)\hat{}0.16) * (\mathrm{T} - 37)$$

where T is air temperature in degree Celsius and V is wind-speed in m/s.

Results

Tables 1 and 2 show the descriptive statistics for daily hospital admissions, meteorological variables, and air pollutants between 1st October and 31st March in 2001–2017. The maximum number of daily hospital admissions was

Table 1 Daily number of hospital admissions for cardiorespiratory diseases during cold season (October–March) in the Helsinki metropolitan area, Finland, 2001–2017

Disease	All-ages			Age ≥ 75 years		
	Median	Min	Max	Median	Min	Max
Cardiovascular						
All	26	2	71	13	1	40
MI	3	0	17	1	0	10
IHD	6	0	25	3	0	14
Cerebrovascular	5	0	18	2	0	11
Arrhythmia	4	0	14	2	0	10
Respiratory						
All	23	0	92	7	0	42
Asthma	1	0	14	0	0	6
COPD	3	0	13	1	0	7
Pneumonia	7	0	32	3	0	17

MI myocardial infarction, *IHD* ischemic heart disease, *COPD* chronic obstructive pulmonary disease

Table 2 Daily levels of air temperature, barometric pressure, and air pollutants during cold season (October–March) in the Helsinki metropolitan area, Finland, 2001–2017

	Mean	Median	Min	Max	SD	Missing values
Meteorology						
Temperature (°C)	1.0	0.0	− 25.0	13.4	6.4	0
Barometric pressure (hPa)	1012.1	1012.0	968.3	1055.0	13.9	0
Air pollution (μg/m^3)						
Ozone	58.5	58.2	4.7	127.9	17.0	85
$PM_{2.5}$	8.3	6.5	0	54.1	5.8	55
PM_{10}	13.9	11.8	0.8	116.2	8.1	56
NO_2	23.5	21.2	3.9	109.5	10.9	26

Min. minimum, *Max.* maximum, *SD* standard deviation, *PM_{10}* inhalable particulate matter, *$PM_{2.5}$* fine particulate matter

highest for all respiratory diseases and lowest for COPD, i.e., 92 and 13, respectively. The average daily temperature during the study period was − 1.0 °C. Daily mean concentrations of ozone, PM_{10}, $PM_{2.5}$, and NO_2 were 58.5, 8.3, 13.9, and 23.5 μg/m^3, respectively.

Figure 1a and b show the overall cumulative association of low daily mean temperature with hospital admissions due to cardiorespiratory diseases for a lag period of 21 days. An increased risk of myocardial infarction (RR: 1.017, 95% CI: 1.002, 1.032) was observed among all ages. We also found an increased risk for all respiratory diseases (RR: 1.012, 95% CI: 1.002, 1.022) and COPD (RR: 1.031, 95% CI: 1.006, 1.056) among elderly people, i.e., in the ≥ 75 years age group. These associations were not sensitive to further adjustment for cold spells: confidence intervals got slightly wider, but the effect estimates for daily temperature remained essentially the same (Table S1 in supplements).

The association of cold spell days with cardiorespiratory admissions is shown in Table S2 (supplement attachment). Cold spell days, where the 10th percentile of the temperature distribution was used as a cutoff point, showed no association with cardiorespiratory hospitalizations in the all-ages group. However, an increased risk was found for COPD admissions (RR: 1.569, 95% CI: 1.013, 2.432) in the ≥ 75 years age group.

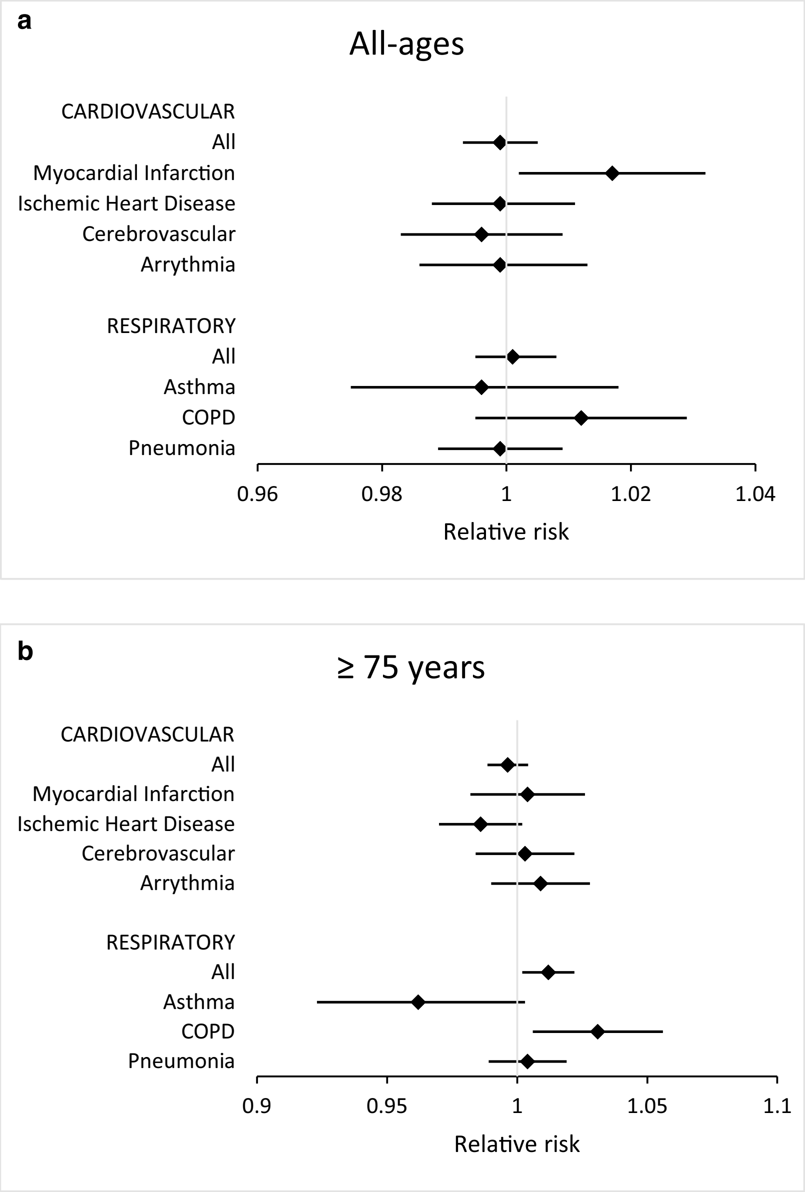
For the more intense cold spell days, where the 5th percentile (Table S3) of the temperature distribution was used as a cutoff point, we found no positive association for any of the disease categories. However, after adjustment for daily mean temperature, intense cold spells showed an association for asthma admissions in the all-ages group (RR: 2.348, 95% CI: 1.026, 5.372) (Fig. 2a and b).

We tested the robustness of our results by running the sensitivity analyses as described in the “Sensitivity analyses” section. All results remained stable except for the 28-day lag period which showed increased risk for ischemia and myocardial infarction admissions (Table S4 and S5 in supplements).

Discussions

This study examined the associations of daily mean temperature in the cold season and cold spells with cardiorespiratory hospital admissions in the Helsinki metropolitan area, Finland. Low daily mean temperatures

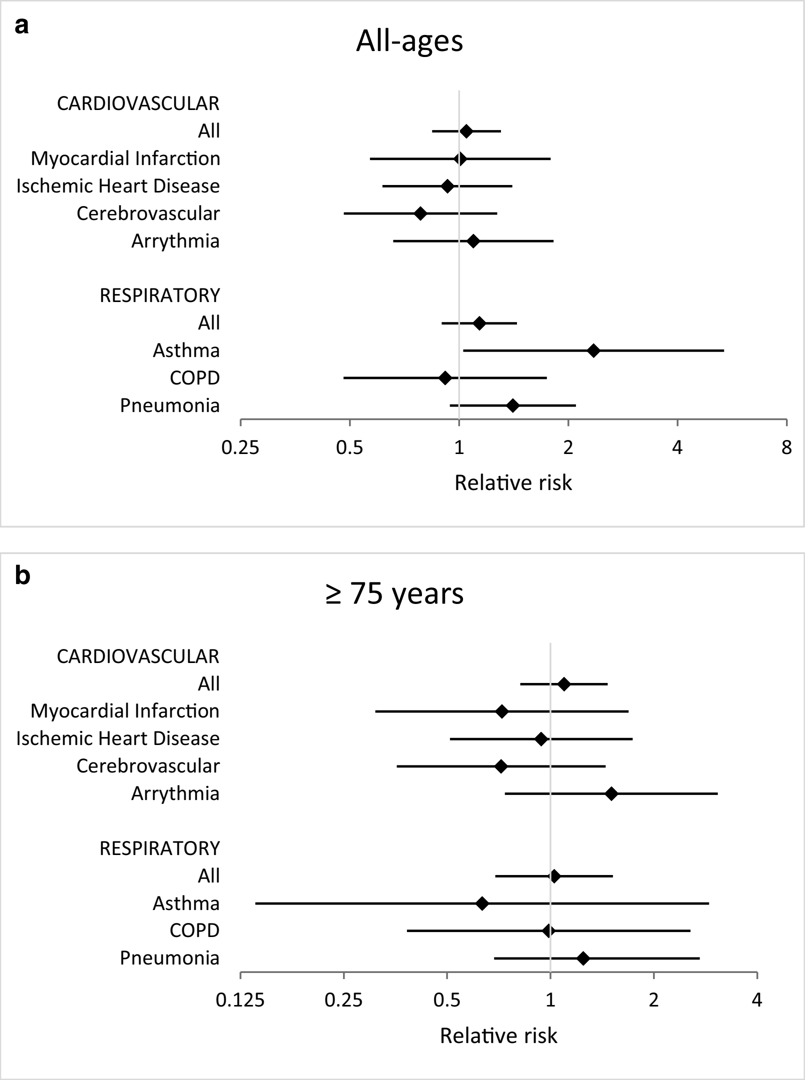
Fig. 1 Relative risk (RR, with 95% confidence interval [95% CI]) of daily hospital admissions for cardiorespiratory diseases per 1 °C decrease in daily mean temperature during cold season (October–March) in the Helsinki metropolitan area, Finland, 2001–2017



were associated with an elevated cumulative risk (over 21 days) for myocardial infarction, all respiratory diseases, and COPD admissions. Cold spells (10th percentile cutoff point) presented an increased risk for COPD admissions, only in the models unadjusted for daily mean temperature. After adjustment for daily mean temperature, intense cold spells (5th percentile cutoff) showed an elevated risk for asthma admissions.

Hospitalizations due to cardiovascular diseases in general showed no association with low winter temperatures or cold spells. Previously, a meta-analysis (including locations such as Italy, California, UK, Brazil, and Hong Kong) restricted to elderly people suggested a reduction in the risk for most CVD morbidity outcomes with decreasing temperature (Bunker et al. 2016). A study in Spain reported that cold exposure increased hospital admissions for cardiovascular

Fig. 2 **a**, **b** Adjusted relative risk of daily hospital admissions for cardiorespiratory diseases associated with cold spell days (5th percentile) during cold season (October–March) in the Helsinki metropolitan area, Finland, 2001–2017



diseases in warmer regions but not in colder ones (Martinez-Solanas and Basagana 2019). Findings from studies on cold and mortality also suggest that variation in the effects may be related to differences between geographical areas (Moghadamnia et al. 2017). People and societies in colder climates are already acclimatized to very low wintertime temperatures, and cold countries, such as Finland, have efficient heating systems in private and nursing homes. During extremely cold winter, people may then just stay indoors which would protect especially vulnerable people.

The associations of daily wintertime temperatures with acute exacerbations of cardiovascular diseases may vary depending on the type of cardiovascular disease. Our results showed that lower daily mean temperatures were only associated with an increased risk of myocardial infarction in the all-ages group. These results align with studies from England and Wales and Beijing, China, showing that low temperatures were associated with an increased risk of myocardial infarction morbidity (Bhaskaran et al. 2010; Liu et al. 2018). Our sensitivity analysis indicated a risk not only for myocardial infarction but also for ischemia when lagged effect up to 28 days was considered. Several plausible physiological mechanisms may explain an increased risk of myocardial infarction or ischemic heart disease in general, at low temperatures. Clinical studies have shown that cold exposure increases arterial pressure and blood viscosity (Keatinge et al. 1984), which leads to an additional need for oxygen causing an increase in cardiac workload (Raven et al. 1970) and may lead ischemia and consequently to myocardial infarction.

Our findings also showed an increased risk of respiratory diseases and COPD admissions in the oldest age category (≥ 75 years old) in association with low daily mean temperatures. There are a limited number of studies available on the association of cold with respiratory morbidity. However, a meta-analysis of studies on elderly people also reported that a decrease in daily mean temperature was associated with the risk for respiratory morbidity (Bunker et al. 2016). One plausible explanation for the adverse respiratory effects is that exposure to low temperature can cause bronchoconstriction and congestion of the airways which may lead to exacerbation of respiratory diseases such as COPD (Giesbrecht 1995). This biological mechanism as well as the greater vulnerability of the elderly in general could explain the strong association of low temperature with respiratory morbidity in our study. However, further research is needed to investigate the etiological mechanisms associated with adverse respiratory outcomes in the elderly.

Cold spells did not show an increased risk for any of the diseases except for COPD admission in models unadjusted for daily mean temperature. However, we found an added effect of cold spells only for asthma admissions in the oldest age category (≥ 75 years of age), and only using the stricter criteria (5th percentile cutoff point). Previously, a study from China found no evidence of an added effect of cold spells in relation to respiratory emergency department visits (Song et al. 2018). Similarly, a systematic review of mortality studies also found no additional effect of prolonged exposure to extreme cold temperatures (Ryti et al. 2016). This may suggest that cold days during prolonged cold periods are not generally associated with a greater risk of adverse health effects than isolated cold days. However, there is limited scientific evidence concerning the additional effect of cold spells on different morbidity outcomes which demands further studies in the future.

Finland is a North European country with extremely low wintertime temperatures and the Finnish population has acclimatized to the cold climate. On the other hand, we analyzed effects in the Helsinki region, which is one of the warmest regions in Finland. Nevertheless, our results suggest that low daily mean temperatures during wintertime still pose a threat to the health of the population in the Helsinki region. It is also possible that changing weather conditions in the region are making people more acclimatized to warm weather, resulting in increased vulnerability for cold temperatures.

Our study has several strengths. To the best of our knowledge, this is the first study to investigate the effects of cold on cardiorespiratory hospital admissions in Northern Europe. Long time-series data with practically a hundred percent coverage of hospital admissions was used to provide reliable population-level estimates. Moreover, we investigated associations of temperature with cause-specific diagnosis rather than broad disease categories. The effects of potential confounders, such as influenza and air pollution, were controlled. However, there are some limitations in our study as well. The number of hospital admissions was low in younger age groups. Hence, we were only able to include people older than 75 years in the age-stratified analysis. Furthermore, only cardiovascular and respiratory admissions were considered. There is a need to investigate the effect of exposure to low temperature also on hospital admissions due to other diseases such as diabetes or kidney function.

Conclusion

Low temperatures during cold days are associated with increased morbidity also in a northern climate. Cold days increase the need for acute hospital care due to myocardial infarction and respiratory causes. We did not find any evidence of an added effect of cold spells, except for asthma.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11869-022-01259-z.

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Data Availability If needed, data and material can be requested from corresponding author.

Declarations

Ethics approval and consent to participate Since this study was a population level study with no personal level data, therefore ethical approval was not required.

Consent for publication All authors have agreed and given consent for publication of this manuscript.

Competing interests The authors declare no competing interests.

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Supplementary material:

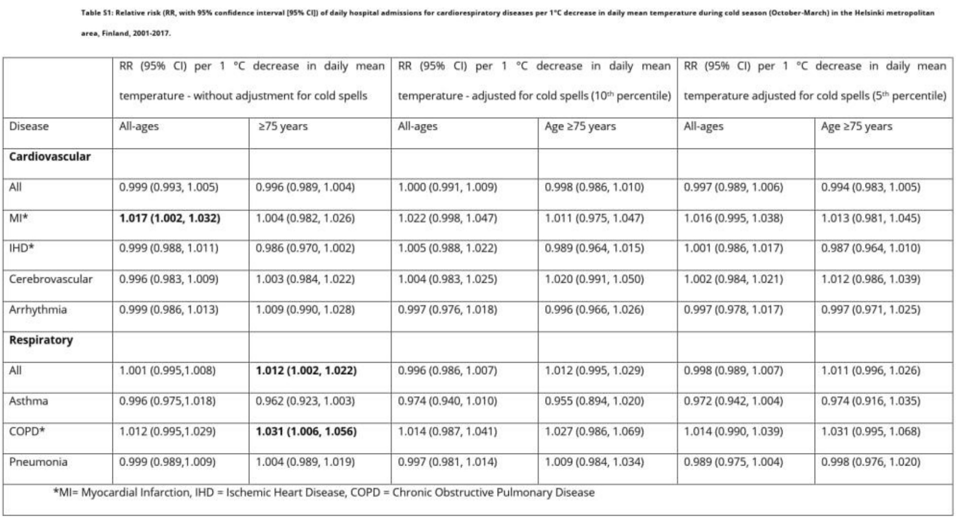
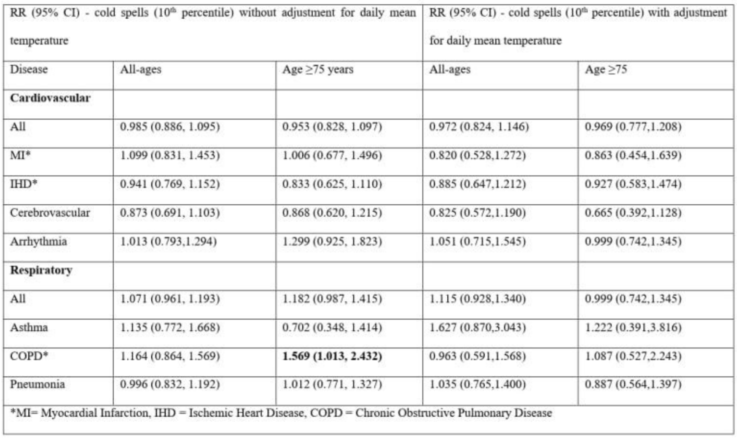


Table S1: Relative risk (RR, with 95% confidence interval [95% CI]) of daily hospital admissions for cardiorespiratory diseases per 1°C decrease in daily mean temperature during cold season (October-March) in the Helsinki metropolitan area, Finland, 2001-2017.

	RR (95% CI) per 1 °C decrease in daily mean temperature - without adjustment for cold spells		RR (95% CI) per 1 °C decrease in daily mean temperature - adjusted for cold spells (10th percentile)		RR (95% CI) per 1 °C decrease in daily mean temperature adjusted for cold spells (5th percentile)	
Disease	All-ages	≥75 years	All-ages	Age ≥75 years	All-ages	Age ≥75 years
Cardiovascular						
All	0.999 (0.993, 1.005)	0.996 (0.989, 1.004)	1.000 (0.991, 1.009)	0.998 (0.986, 1.010)	0.997 (0.989, 1.006)	0.994 (0.983, 1.005)
MI*	**1.017 (1.002, 1.032)**	1.004 (0.982, 1.026)	1.022 (0.998, 1.047)	1.011 (0.975, 1.047)	1.016 (0.995, 1.038)	1.013 (0.981, 1.045)
IHD*	0.999 (0.988, 1.011)	0.986 (0.970, 1.002)	1.005 (0.988, 1.022)	0.989 (0.964, 1.015)	1.001 (0.986, 1.017)	0.987 (0.964, 1.010)
Cerebrovascular	0.996 (0.983, 1.009)	1.003 (0.984, 1.022)	1.004 (0.983, 1.025)	1.020 (0.991, 1.050)	1.002 (0.984, 1.021)	1.012 (0.986, 1.039)
Arrhythmia	0.999 (0.986, 1.013)	1.009 (0.990, 1.028)	0.997 (0.976, 1.018)	0.996 (0.966, 1.026)	0.997 (0.978, 1.017)	0.997 (0.971, 1.025)
Respiratory						
All	1.001 (0.995,1.008)	**1.012 (1.002, 1.022)**	0.996 (0.986, 1.007)	1.012 (0.995, 1.029)	0.998 (0.989, 1.007)	1.011 (0.996, 1.026)
Asthma	0.996 (0.975,1.018)	0.962 (0.923, 1.003)	0.974 (0.940, 1.010)	0.955 (0.894, 1.020)	0.972 (0.942, 1.004)	0.974 (0.916, 1.035)
COPD*	1.012 (0.995,1.029)	**1.031 (1.006, 1.056)**	1.014 (0.987, 1.041)	1.027 (0.986, 1.069)	1.014 (0.990, 1.039)	1.031 (0.995, 1.068)
Pneumonia	0.999 (0.989,1.009)	1.004 (0.989, 1.019)	0.997 (0.981, 1.014)	1.009 (0.984, 1.034)	0.989 (0.975, 1.004)	0.998 (0.976, 1.020)

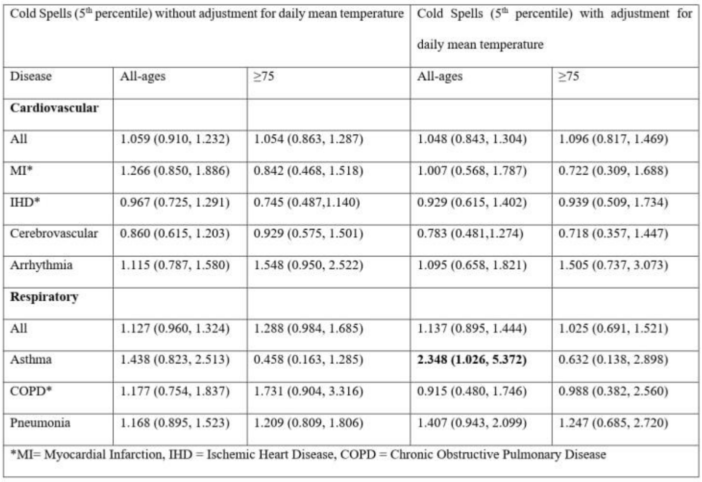
*MI= Myocardial Infarction, IHD = Ischemic Heart Disease, COPD = Chronic Obstructive Pulmonary Disease

Table S2: Relative risk (RR, with 95% confidence interval [95% CI]) of daily hospital admissions for cardiorespiratory diseases associated with cold spell days (10th percentile) during the cold season (October-March) in the Helsinki metropolitan area, Finland, 2001-2017.



RR (95% CI) - cold spells (10th percentile) without adjustment for daily mean temperature			RR (95% CI) - cold spells (10th percentile) with adjustment for daily mean temperature	
Disease	All-ages	Age ≥75 years	All-ages	Age ≥75
Cardiovascular				
All	0.985 (0.886, 1.095)	0.953 (0.828, 1.097)	0.972 (0.824, 1.146)	0.969 (0.777,1.208)
MI*	1.099 (0.831, 1.453)	1.006 (0.677, 1.496)	0.820 (0.528,1.272)	0.863 (0.454,1.639)
IHD*	0.941 (0.769, 1.152)	0.833 (0.625, 1.110)	0.885 (0.647,1.212)	0.927 (0.583,1.474)
Cerebrovascular	0.873 (0.691, 1.103)	0.868 (0.620, 1.215)	0.825 (0.572,1.190)	0.665 (0.392,1.128)
Arrhythmia	1.013 (0.793,1.294)	1.299 (0.925, 1.823)	1.051 (0.715,1.545)	0.999 (0.742,1.345)
Respiratory				
All	1.071 (0.961, 1.193)	1.182 (0.987, 1.415)	1.115 (0.928,1.340)	0.999 (0.742,1.345)
Asthma	1.135 (0.772, 1.668)	0.702 (0.348, 1.414)	1.627 (0.870,3.043)	1.222 (0.391,3.816)
COPD*	1.164 (0.864, 1.569)	**1.569 (1.013, 2.432)**	0.963 (0.591,1.568)	1.087 (0.527,2.243)
Pneumonia	0.996 (0.832, 1.192)	1.012 (0.771, 1.327)	1.035 (0.765,1.400)	0.887 (0.564,1.397)
*MI= Myocardial Infarction, IHD = Ischemic Heart Disease, COPD = Chronic Obstructive Pulmonary Disease				

Table S3: Relative risk of daily hospital admissions for cardiorespiratory diseases associated with cold spell days (5th percentile) during cold season (October-March) in the Helsinki metropolitan area, Finland, 2001-2017.



Cold Spells (5th percentile) without adjustment for daily mean temperature			Cold Spells (5th percentile) with adjustment for daily mean temperature	
Disease	All-ages	≥75	All-ages	≥75
Cardiovascular				
All	1.059 (0.910, 1.232)	1.054 (0.863, 1.287)	1.048 (0.843, 1.304)	1.096 (0.817, 1.469)
MI*	1.266 (0.850, 1.886)	0.842 (0.468, 1.518)	1.007 (0.568, 1.787)	0.722 (0.309, 1.688)
IHD*	0.967 (0.725, 1.291)	0.745 (0.487,1.140)	0.929 (0.615, 1.402)	0.939 (0.509, 1.734)
Cerebrovascular	0.860 (0.615, 1.203)	0.929 (0.575, 1.501)	0.783 (0.481,1.274)	0.718 (0.357, 1.447)
Arrhythmia	1.115 (0.787, 1.580)	1.548 (0.950, 2.522)	1.095 (0.658, 1.821)	1.505 (0.737, 3.073)
Respiratory				
All	1.127 (0.960, 1.324)	1.288 (0.984, 1.685)	1.137 (0.895, 1.444)	1.025 (0.691, 1.521)
Asthma	1.438 (0.823, 2.513)	0.458 (0.163, 1.285)	**2.348 (1.026, 5.372)**	0.632 (0.138, 2.898)
COPD*	1.177 (0.754, 1.837)	1.731 (0.904, 3.316)	0.915 (0.480, 1.746)	0.988 (0.382, 2.560)
Pneumonia	1.168 (0.895, 1.523)	1.209 (0.809, 1.806)	1.407 (0.943, 2.099)	1.247 (0.685, 2.720)
*MI= Myocardial Infarction, IHD = Ischemic Heart Disease, COPD = Chronic Obstructive Pulmonary Disease				

Table S4: Relative risk (RR, with 95% confidence interval [95% CI]) of daily hospital admissions for cardiorespiratory diseases per 1°C decrease in daily mean temperature (Lag 0-14) during cold season (October-March) in the Helsinki metropolitan area, Finland, 2001-2017.

	RR (95% CI) per 1 °C decrease in daily mean temperature (Lag 0-14)	
Disease	All-ages	≥75 years
Cardiovascular		
All	0.993(0.985, 1.002)	0.985(0.974, 0.997)
MI*	0.994(0.972, 1.016)	0.967(0.936, 1.000)
IHD*	0.988(0.973, 1.004)	0.962(0.940, 0.985)
Cerebrovascular	0.990(0.972, 1.008)	0.995(0.970, 1.022)
Arrhythmia	1.004(0.984, 1.024)	1.016(0.989, 1.045)
Respiratory		
All	1.003(0.994, 1.013)	1.013(0.998, 1.029)
Asthma	1.011(0.978, 1.045)	0.966(0.910, 1.026)
COPD*	1.010(0.985, 1.036)	1.041(1.004, 1.080)
Pneumonia	1.001(0.986, 1.016)	1.011(0.989, 1.034)
*MI= Myocardial Infarction, IHD = Ischemic Heart Disease, COPD = Chronic Obstructive Pulmonary Disease		

Table S5: Relative risk (RR, with 95% confidence interval [95% CI]) of daily hospital admissions for cardiorespiratory diseases per 1°C decrease in daily mean temperature (Lag 0-28) during cold season (October-March) in the Helsinki metropolitan area, Finland, 2001-2017.

	RR (95% CI) per 1 °C decrease in daily mean temperature (Lag 0-28)	
Disease	All-ages	≥75 years
Cardiovascular		
All	1.002(0.997, 1.007)	0.999 (0.994, 1.005)
MI*	1.021(1.010, 1.031)	1.015(0.999, 1.031)
IHD*	1.011(1.003, 1.019)	1.002(0.991, 1.014)
Cerebrovascular	1.007(0.997, 1.016)	1.009(0.996, 1.023)
Arrhythmia	0.998(0.988, 1.008)	1.008(0.994, 1.022)
Respiratory		
All	1.000(0.996, 1.005)	1.004(0.996, 1.011)
Asthma	0.995(0.979, 1.011)	0.985(0.955, 1.015)
COPD*	1.009(0.997, 1.021)	1.017(1.000, 1.036)
Pneumonia	0.996(0.989, 1.004)	0.999(0.988, 1.010)
*MI= Myocardial Infarction, IHD = Ischemic Heart Disease, COPD = Chronic Obstructive Pulmonary Disease		

6 Association between ambient temperature and self-perceived health status in Southern Germany: Results from KORA FIT study

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Abstract:

Background: Short-term exposure to low and high air temperatures can cause serious harmful effects on human health. Existing literature has mostly focused on associations of ambient air temperature with mortality and the need for health care in population-level studies. Studies that have considered self-perceived health status as an outcome when examining the effects of air temperature on health are scarce. In this study, we explored the short-term association of daily mean air temperature with various measures of self-perceived health status. Methods: This cross-sectional analysis is based on the Cooperative Health Research in the Region of Augsburg (KORA) FIT study conducted in 2018/2019 and included participants from the Augsburg region of Southern Germany. Health-related quality of life (HRQOL) was evaluated using the EuroQol Five Dimension (EQ-5D) questionnaire. Self-rated health (SRH) and comparative self-rated health (CSRH) were each assessed using a single question. Daily mean air temperature data was estimated using a spatiotemporal model and assigned to participants' home addresses at a resolution of 1× 1km. Regression models with a Distributed Lag Non-linear Modeling (DLNM) approach were used to investigate the associations between daily mean air temperature and self-perceived health measures. Results: The mean temperature during our study period was 9.2°C, and the mean age of the participants was 64 years. We found no association of heat or cold with the HRQOL, SRH or CSRH. Nevertheless, there was a significant protective association of low air temperature with the EQ-5D dimension “usual activities.” Conclusion: There was no evidence of daily mean air temperature adversely affecting participants' self-perceived health status.

Keywords: EQ-5D, self-rated health, self-perceived health, HRQOL, ambient air temperature

Introduction

Climate change and changing weather conditions have become a serious public health concern. Extreme high and low air temperatures are known to increase morbidity and mortality (1,2,3). As air temperature is increasing globally (4), temperature-associated health burden demands even more scientific research to investigate potential health risks (5).

The effect of extreme air temperatures on human health is considered a key research priority worldwide (6). Exposure to high air temperatures affects the body's natural mechanism to regulate its internal temperature leading to heat stress, hyperthermia, heat stroke, and ultimately causing death (7). Likewise, exposure to low air temperatures can cause increased blood pressure, vasoconstriction, blood viscosity, and plasma fibrinogen, which may lead to adverse cardiovascular events (8). Low air temperature can also induce bronchoconstriction, suppress immunological mechanisms, and increase respiratory infection risk (9).

Health-related quality of life (HRQOL) is a multidimensional concept describing an individual's health in different domains and has been used in many previous studies (10, 11, 12). HRQOL can be measured using tools like the EuroQol Five Dimensions questionnaire (EQ-5D) (13). This questionnaire covers five domains related to physical and mental health. In addition to EQ-5D, self-rated health (SRH) and comparative self-rated health (CSRH) are further measures to investigate self-perceived health status. Self-perceived health is a widely used subjective health concept that covers all aspects of health following the definition of the World Health Organization (WHO), i.e., an individual's biological, social, and mental well-being (14). Clinicians usually overlook subjective self-reported scales since they are considered less reliable than objectively evaluated health measures (15, 16, 17). However, existing literature has shown that subjective health scales can strongly predict mortality (18, 19) and effectively represent the individual's perception of his/her daily life quality and health (20, 21).

Traditionally, clinical diagnoses or results of physiological measurements have been used to indicate morbidity in studies on the health effects of air temperature. However, these do not represent the individual's perception of their life and health. To the best of our knowledge, only one study from China has investigated the short-term association of ambient air temperature with HRQOL or self-rated health (22). They reported that exposure to high temperatures and temperature fluctuations decreased the self-rated health scores, which referred to body pain and impairments of usual activities due to physical or mental health reasons in the past month (22). Additionally, only three other studies have investigated the association of short-term indoor air temperature with self-rated health. These studies concluded that exposure to high or low indoor air temperatures could cause lower self-rated health scores (23,24,25). In this study, we therefore investigated whether ambient temperature is associated with self-perceived health measures of participants in the Augsburg region of Southern Germany.

Methods

Study population

This cross-sectional study is based on data collected in the population-based Cooperative Health Research in the Region of Augsburg (KORA) cohort study, Germany (26). Four cross-sectional surveys of KORA (S1: 1984/1985, S2: 1989/1990, S3: 1994/1995, S4: 1999/2000) and multiple follow-ups have been conducted since 1984. The KORA FIT follow-up study was conducted from January 2018 to June 2019, comprising all KORA participants born between 1945 and 1964. We excluded KORA participants who were deceased, moved outside the study area, or moved to an unknown address before the KORA FIT examination, leaving 4748 individuals eligible for the KORA-FIT survey. Of these, 365 individuals could not be reached, 394 did not have time, and 930 were unwilling to participate. We re-examined the remaining 3059 participants in the KORA-FIT survey (64.4% of all eligible individuals).

Our study analyzed a subgroup of KORA FIT participants involved in the INGER project (N=2,624). The INGER project (https://www.uni-bremen.de/en/inger, accessed on 20th December 2022) aimed to integrate sex/gender themes into environmental health research and collected data via a newly developed questionnaire with modules on diverse biological and social aspects of gender along with information on green spaces. We further excluded participants lacking geocoding information, having missing data in outcomes, or having missing data in covariates in the main model, resulting in 2,602 participants in this study. The exclusion process is shown in Figure 1.

Personal and clinical characteristics, medication intake, and disease history were collected through self-administrated questionnaires, interviews, and physical examinations at the study center. The ethics committee of the Bavarian Chamber of Physicians approved the study (KORA-Fit EC No 17040). All study participants gave written informed consent, and the study was performed in accordance with the Declaration of Helsinki.

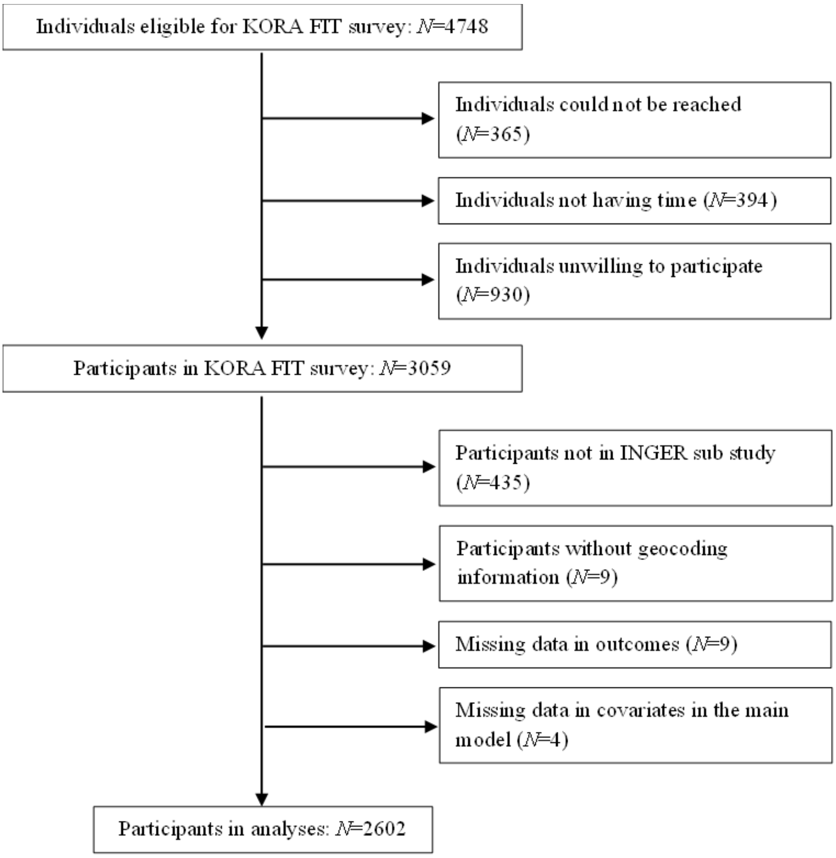

Figure 1: Flow chart of number of participants in the KORA INGER Project

Outcomes

As an outcome measure, we assessed HRQoL using the EQ-5D instrument (27). It contains a descriptive system asking five key questions on mobility, self-care, usual activities, pain/discomfort, and anxiety/depression, which were answered by the participants themselves. We used the EQ-5D-5L version, in which each dimension has five answer levels: no problems, slight problems, moderate problems, severe problems, and unable or extreme problems. An EQ-5D index value was calculated to represent the health status as a single number. The calculation of the index value was done using the German value set developed by Ludwig et al. (28). The range of the index value in our study was +1.000 to -0.131 (a lower number indicates worse health status). The EQ-5D instrument also includes a measure of SRH: a visual analog scale (EQ-VAS), on which participants were asked to mark their current health status between 0 (worst imaginable health) and 100 (best imaginable health).

In the analyses using individual dimensions as outcomes, the five answer levels were dichotomized as “no problems” (level 1), and slight, moderate, severe, and unable or extreme problems (level 2 to level 5) were merged into “any problems” as per EQ-5D-5L user guidelines (29).

Self-rated health (SRH) was assessed using a single question, “How would you rate your current physical condition?” with responses on a 4-point scale: very good, good, less good, and bad. We dichotomized responses to 0 = good by merging very good and good and 1 = bad by merging less good and bad.

Comparative self-rated health (CSRH) was also assessed by a single question, “How would you rate your health in comparison to other people of your age?” with responses on a 4-point scale: better, worse, the same, I don’t know. The response was dichotomized with the values 0=better by merging better, the same, and I don’t know and 1= worse.

Exposure

In this study, our exposure of interest was daily mean ambient air temperature. The daily mean air temperature was estimated at a resolution of 1 × 1 km using a spatio-temporal model and assigned to participants’ home addresses. Daily mean air temperature was estimated using a multi-stage regression-based approach and a combination of satellite land surface temperature data, ground-based air temperature measurements, and various remote sensing spatial predictors (30). Especially for the Augsburg region, our study area, the mean air temperature model was extensively validated against an independent and dense monitoring network of 82 stations and achieved very good performance (R2 = 0.99 and Root Mean Square Error = 1.07oC).

Covariates

Previous literature was used to obtain information about potential confounders. We used month, year, weekday age, sex, socioeconomic status, living with a partner, physical activity, BMI, history of diabetes, angina pectoris, asthma, fine particulate matter ($PM_{2.5}$; aerodynamic diameter ≤ 2.5 μm), and ozone (O_3) as covariates.

Age was used as a continuous variable. Sex was operationalized dichotomously with the categories “female” and “male” without further distinguishing between biological sex or gender being related to social and structural factors. Socioeconomic status was measured using the Helmert Index (low score shows poor socioeconomic status) (31). Living with a partner was categorized as yes or no.

Physical activity was divided into four levels, i.e., regularly more than 2 hours a week, regularly about 1 hour a week, irregularly approximately 1 hour a week, and almost no or no physical activity. Body Mass Index (BMI) was included as a continuous variable measured in kg/m^2.

Medical history variables included history of angina, diabetes, or asthma as binary variables i.e., yes or no.

Data on daily NO_2 concentrations were obtained from an urban background station (BourgesPlatz) located 2 km north of the city center. O_3 concentrations were measured at the monitoring station located approximately 4 km south of the city center. Daily average $PM_{2.5}$ ($PM_{2.5}$; aerodynamic diameter ≤ 2.5 μm) was obtained from an aerosol monitoring station located 1 km southeast of the city center. This monitoring station was established in 2004 and is considered a representative of the urban background in Augsburg.

Statistical Analysis

We used regression models with the distributed lag non-linear modeling (DLNM) approach to explore the association of daily mean air temperature with EQ-5D index value and EQ-VAS. The DLNM uses a “cross-over basis” function to simultaneously define the shape of the association of the dependent variable with the independent variable and the time lag structure.

A lag period of 21 days was selected to capture the overall and delayed effect of temperature as well. For the cross-basis, we defined air temperature with a natural cubic spline having three knots placed at the 25th, 50th, and 75th percentile. Natural cubic splines with three knots placed at equally spaced positions were used to investigate the lag structure. In the second analysis stage, we investigated the association of daily mean air temperature with individual dichotomized dimensions of EQ-5D-5L, as well as SRH and CSRH. Since the outcome variables were dichotomous, we incorporated multiple logistic regression model with the DLNM approach to estimate the effects.

A stepwise forward selection method reducing the Bayesian Information Criterion (BIC) was used to select covariates from a large set of potential covariates. The selection process was done in four steps. In the first step, we ran the model with age, sex, living with a partner, education years, income, working status, and socioeconomic status offered for selection. In the second step, we offered BMI, physical activity, smoking status, and alcohol consumption. In the third step, a history of hypertension, diabetes mellitus, myocardial infarction, angina pectoris, COPD, and asthma were offered for selection. In the final step, we offered air pollutants such as PM_{10}, $PM_{2.5}$, O_3, and NO_2. The selection process was carried out with each of the outcomes. There was only one final model for all outcomes consisting of all the covariates resulting from outcome-specific selection processes. The final model included the following covariates: age, sex, socioeconomic status, living with a partner, physical activity in categories, BMI, angina, diabetes, asthma, $PM_{2.5}$, and ozone (O_3). In addition to these, month, year, and weekday covariates were also included in the final model to control time and seasonal trends.

All the analyses were performed using the R program for statistical computing (version 1.4.1106) with the packages “mgcv” and “dlnm” (32, 33). Results were reported as absolute differences and odds ratios with 95% confidence intervals for moderate and more extreme heat and cold.

Sensitivity Analyses

As sensitivity analyses, we varied the modeling parameters and used a 14-day lag period for daily mean temperature. Additionally, we ran the models by placing the knots for the exposure-response function at the 10th, 25th, 50th, and 75th percentile. We also checked the robustness of our results by introducing NO_2 as a covariate in the model. As an additional sensitivity check, we investigated effect modification by incorporating an interaction term between the cross-basis of air temperature and the effect modifier in the regression model. The potential effect modifiers included age (<65 years vs. >= 65 years), sex (male vs. female), comorbidity (angina pectoris, asthma, and diabetes mellitus), and self-reports on green spaces (greenness of the participants’ neighborhood and access to public green spaces) (supplementary file 1.1).

Results

Tables 1 and 2 show the basic descriptive statistics of the study population and exposure variables. The mean age of the participants was 64 years with 54.6% male and 45.4% female. Moreover, the average socioeconomic status of the participants was 14.9 which reflects a medium status as per the global Helmert index. The daily mean air temperature during the study period was 9.2± 7.9°C. The average daily concentrations of $PM_{2.5}$, PM_{10}, O_3, and NO_2 were 14.2, 19.7, 46.5, and 28.2 µg/m3, respectively.

Table 1: Descriptive statistics of the study population (N= 2602)

Variable (unit)	**Mean ± SD or N (%)**
Personal characteristics	
Age (years)	64.0 ± 5.4
Sex	
Male	1420 (54.6)
Female	1182 (45.4)
Live with a partner	
Yes	2058 (79.1)
No	544 (20.9)
Socioeconomic status [c]	14.9 ± 5.0
Physical activity	
regularly more than 2 hours a week	1015 (39.0)
regularly about 1 hour a week	885 (34.0)
irregularly approx. 1 hour a week	320 (12.3)
almost no or no physical activity	382 (14.7)
Body Mass Index (BMI, kg/m^2)	28.0 ±5.2
Disease history [d]	
Angina pectoris	
Yes	99 (3.8)
No	2493 (95.8)
Diabetes mellitus	
Yes	206 (7.9)
No	2393(92.0)
Bronchial asthma	
Yes	207 (8.0)
No	2335(89.7)
Outcomes	
HRQOL: EQ-5D-5L index value [a]	0.9 ± 0.1
Dichotomized EQ-5D-5L dimensions	

• **Mobility**	
Problem in walking around	725 (27.9)
• **Self-care**	
Problem in washing or dressing	84 (3.2)
• **Usual activities**	
Problem in doing day to day activities	364 (14.0)
• **Pain/Discomfort**	
Have pain or discomfort	1612 (62.0)
• **Anxiety/Depression**	
Have anxiety or depression	705 (27.1)
HRQOL: EQ VAS scale [b]	79.2±14.6
Self-rated health: physical health	
having a bad physical condition	435 (16.7)
Self-rated health: Comparative health	
Worse in comparison to own age group	210 (8.1)

[a] EQ-5D-index value: +1 to -0.131 (lower numbers indicate poor health status)

[b] EQ-VAS: Scale from 0 to 100 (0 is the worst health)

[c] Individual socioeconomic status (SES) according to Helmert index

[d] Missing data: angina pectoris: 10 observations (0.4%), diabetes mellitus: 3 observations (0.1%), bronchial Asthma: 60 observations (2.3%)

Table 2: Descriptive statistics of environmental variables

Variable (Units)	**Mean ± SD**
Air temperature (°C)	9.2± 7.9
Air pollutants (μg/m^3)	
$PM_{2.5}$	14.2±9.3
O_3	46.5±23.8
NO_2	28.2±11.0

We analysed the association of daily mean air temperature with EQ-5D index value and the dichotomized EQ-5D-5L dimensions. The results of our analysis are shown in Table 3. The daily mean air temperature was not associated with the EQ-5D index value in any temperature range of our study.

However, we found a significant effect of moderate cold (OR: 0.38, 95% CI: 0.18, 0.84) and extreme cold (OR: 0.13, 95% CI: 0.02, 0.93) with the dimension "usual activities." We did not report effect estimates for one EQ-5D-5L domain, i.e., "problem in taking care of yourself," as there were a very limited number of observations. Additionally, our results did not show any association of daily mean temperature with the EQ-VAS, SRH, or CSRH of participants.

Table 3: Absolute changes (95%CI) in EQ-5D-index value and EQ-vas and odds ratios (95%CI) of having any problems in EQ-5D-5L dimensions and of worse SRH and CSRH for the association with daily mean temperature of 21 previous days

Outcome	**Moderate Heat[1]**	**Extreme Heat[2]**	**Moderate Cold[3]**	**Extreme Cold[4]**
EQ-5D index value	-0.010(-0.064, 0.045)	-0.039(-0.151, 0.074)	0.000(-0.029, 0.030)	-0.019(-0.096, 0.058)
EQ-VAS	-2.389(-8.361, 3.582)	-4.401(-16.787, 7.985)	2.253(-1.004, 5.510)	7.025(-1.436, 15.485)
Dichotomized EQ-5D-5L Dimensions				
having problem in mobility	1.01(0.37, 2.74)	1.64(0.21, 13.09)	0.73(0.42, 1.29)	1.20(0.28, 5.24)
having problem in usual activities	1.07(0.29, 3.88)	1.49(0.10, 21.67)	**0.38(0.18, 0.84)**	**0.13(0.02, 0.93)**

having pain/discomfort	0.96(0.38, 2.47)	1.22(0.17, 8.54)	0.84(0.51, 1.38)	0.72(0.20, 2.60)
having anxiety/depression	1.37(0.50, 3.78)	2.08(0.25, 16.94)	0.75(0.43, 1.32)	0.68(0.16, 2.87)
Self-rated health (SRH)	1.08(0.31, 3.83)	1.24(0.09, 17.10)	1.21(0.62, 2.35)	1.69(0.30, 9.46)
Comparative Self-rated health (CSRH)	2.15(0.38, 12.24)	4.90(0.13, 180.07)	0.77(0.31, 1.96)	0.65(0.06, 7.05)

[1] The 95th percentile of air temperature (21.2°C) relative to the 75th percentile of air temperature (16.0°C)

[2] The 99th percentile of air temperature (24.5°C) relative to the 75th percentile of air temperature (16.0°C)

[3] The 5th percentile of air temperature (-3.5 °C) relative to the 25th percentile of air temperature (3.1°C)

[4] The 1st percentile of air temperature (-7.3 °C) relative to the 25th percentile of air temperature (3.1°C)

We confirmed the robustness of our results with sensitivity analyses. Results have been provided in supplementary file 1.1.

Discussion

This study investigated the association of daily mean air temperature with self-perceived health status in the KORA FIT study in Augsburg, Germany. We did not find any increased risk of poor health-related quality of life, assessed by using the EQ-5D-5L questionnaire, or self-rated and comparative self-rated health with heat or cold. However, a protective association of low temperature with the dimension “usual activities” was observed.

We hypothesized that low and high temperatures might be associated with poor self-perceived health. Our findings were contrary to our hypothesis. We found that daily mean temperature is not associated with the self-perceived health status of the participants. However, there has been only one study from China that investigated the association of ambient temperatures with the HRQOL or self-rated health score of the participants. They reported that the participants' self-rated health score decreased with high temperatures and temperature fluctuation (22). However, our results contrast with that study. A possible explanation for contradictory results could be because of differences in the use of health indicators.

Previous studies have shown that high ambient temperatures are correlated with indoor temperature during summertime (34, 35). Chen et al. reported that there is only a little air conditioning in residential buildings in Augsburg, which should make people more vulnerable to heat and high temperatures (36). In contrast to what could be concluded based on our results, studies have found high indoor temperature to be associated with decreased SRH. For example, a study from England investigated the association of indoor temperature with self-rated health. SRH was assessed by asking a question, “How is your health in general” and participants reported through five answer options “very good, good, fair, bad or very bad”. This study reported that high indoor temperatures cause worse self-rated health (23). Another study from the United States investigated the association of indoor temperatures with self-reported mental health (24). It was assessed by asking a question “Thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?”. They reported that cooler days from the previous month reduce the likelihood of reporting bad mental health, while hotter days increase the probability (24). A potential reason for not finding an association between ambient temperature and self-rated health could be that our study subjects were, in general, in good health, with only a few participants having a history of chronic diseases and not that old, as the mean age was 65 years. Moreover, participants with chronic diseases may have poor self-assessments of their health due to their diseases, and temperature effects might be too weak to be observed beyond that. Additionally, temperatures in our study were perhaps not high enough (Mean: 9.2±, ± SD: 7.9 °C) to cause any potential harm to individuals’ health.

We found no adverse association between high temperatures and the domain “usual activities”. However, a protective effect of moderate and extreme cold on the domain “usual activities” of participants was reported. To the best of our knowledge, there are no previous studies on the association of temperature with the domain “usual activities.” However, previous literature has reported that extreme temperatures can cause physiological effects, which may reduce the capacity to perform daily activities (37, 38). For example, a study investigated the effect of air temperature on labor productivity in telecommunication offices. The study was conducted as a case-control study in two call centers. The intervention was conducted by installing an air conditioner in one call center. Results showed that the call center with no air conditioning and elevated temperature had significantly lower work productivity than the one with an air conditioning work environment. (39). Likewise, in another study, Pepler and Warner found that high temperatures cause the longest time to finish a usual task (40).

Our results also suggested that daily low or high mean temperatures are not associated with the domain “pain or discomfort.” However, we did not find any suitable previous studies to compare our findings. We also did not find any association of temperature with the domain “depression/anxiety.” In contrast to our findings, previous literature has reported that low or high ambient temperatures could increase the risk of depression and mental health problems (41, 42). As previously mentioned, our study participants were generally in good health. People with good health status can cope with stressful situations better, which could be a reason for not finding any association in our study.

This study has several strengths. To the best of our knowledge, only three other studies have evaluated the association of temperature with self-perceived health status. Moreover, this study is based on a well-explored and extensive study population. In addition, a wide range of participants’ information is available from the survey, which allowed us to select the important potential confounders. However, there are some limitations in this study as well. Firstly, information about the participants was collected at a single time point for each individual, so causal relationships cannot be concluded. Secondly, self-rated health is an all-inclusive concept with various influencing variables that might not all have been adequately adjusted.

In conclusion, our study does not indicate any short-term effect of daily mean temperature on self-rated health in the participants of the KORA FIT study in Southern Germany.

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Supplementary Material:

Effect estimates with 14 days lag period:

Outcome	Moderate heat	Extreme heat	Moderate cold	Extreme cold
EQ-5D-5L	0.033(-0.047, 0.053)	-0.007(-0.109, 0.096)	0.012(-0.013, 0.037)	0.020(-0.038, 0.078)
EQ-VAS	-1.093(-6.617, 4.432)	-2.272(-13.552, 9.007)	1.926(-0.843, 4.696)	5.169(-1.198, 11.536)
Comparative SRH	1.98(0.42, 9.20)	4.530(0.19, 105.22)	0.81(0.37, 1.78)	0.98(0.16, 6.02)

Effect estimates with NO_2 in model

Outcome	Moderate heat	Extreme heat	Moderate cold	Extreme cold
EQ-5D-5L	-0.007(-0.061, 0.047)	-0.033(-0.146, 0.079)	0.002(-0.028, 0.031)	-0.014(-0.091, 0.063)
EQ-VAS	-2.101(-8.088, 3.886)	-3.828(-16.243, 8.588)	2.431(-0.836, 5.699)	7.574(-0.927, 16.076)
Comparative SRH	1.81(0.31, 10.56)	3.46(0.09, 134.20)	0.71(0.28, 1.82)	0.50(0.04, 5.66)

Effect estimates with Model having 4 knot locations 10th, 25th, 50th and 75th percentile

Outcome	Moderate heat	Extreme heat	Moderate cold	Extreme cold
EQ-5D-5L	-0.010(-0.064, 0.045)	-0.039(-0.151, 0.074)	0.000(-0.029, 0.030)	-0.019(-0.096, 0.058)
EQ-VAS	-2.389(-8.361, 3.582)	-4.401(-16.787, 7.985)	2.253(-1.004, 5.510)	7.025(-1.436, 15.485)
Comparative SRH	2.15(0.38, 12.24)	4.90(0.13, 180.07)	0.77(0.31, 1.96)	0.65(0.06, 7.05)

Effect modification by chronic disease history and green spaces:

Each of the effect estimates shows odds of having a problem while not having a problem was used a reference category.

1. Outcome: EQ-5D-5L index value

By diabetes mellitus: (having diabetes)

Moderate heat (75th to 95th Percentile)

0.052(-0.046, 0.150)

Extreme heat (75th to 99th percentile)

0.106 (-0.093, 0.305)

Moderate cold (25th to 5th percentile)

0.020(-0.074, 0.114)

Extreme cold (25th to 1st percentile)

0.098(-0.149, 0.344)

By angina Pectoris (having angina)

Moderate heat (75th to 95th Percentile)

0.007 (-0.142, 0.156)

Extreme heat (75th to 99th percentile)

0.004 (-0.303, 0.311)

Moderate cold (25th to 5th percentile)

0.115 (-0.033, 0.263)

Extreme cold (25th to 1st percentile)

0.273 (-0.124, 0.669)

By asthma (having Asthma)

Moderate heat (75th to 95th Percentile)

0.042 (-0.060, 0.145)

Extreme heat (75th to 99th percentile)

0.058 (-0.153, 0.270)

Moderate cold (25th to 5th percentile)

0.053(-0.048, 0.154)

Extreme cold (25th to 1st percentile)

0.084(-0.173, 0.341)

By green space in neighborhood (having green space in neighborhood)

Moderate heat (75th to 95th Percentile)

-0.004 (-0.050, 0.043)

Extreme heat (75th to 99th percentile)

-0.025 (-0.115, 0.066)

Moderate cold (25th to 5th percentile)

-0.004 (-0.030, 0.022)

Extreme cold (25th to 1st percentile)

-0.033 (-0.110, 0.045)

By publicly accessible green spaces (having publicly accessible green spaces)

Moderate heat (75th to 95th Percentile)

-0.005 (-0.053, 0.042)

Extreme heat (75th to 99th percentile)

0.028(-0.120, 0.064)

Moderate cold (25th to 5th percentile)

-0.003 (-0.030, 0.024)

Extreme cold (25th to 1st percentile)

-0.032(-0.111, 0.048)

2. Outcome: Comparative health (0: better, 1= worse) (better = reference category)

By diabetes (having diabetes)

Moderate heat (75th to 95th Percentile)

0.361(0.014, 9.287)

Extreme heat (75th to 99th percentile)

0.104 (0.000, 72.301)

Moderate cold (25th to 5th percentile)

0.041(0.000, 3.568)

Extreme cold (25th to 1st percentile)

0.000(0.000,17.358)

By asthma (having asthma):

Moderate heat (75th to 95th Percentile)

0.386 (0.015, 10.250)

Extreme heat (75th to 99th percentile)

0.313(0.000, 229.574)

Moderate cold (25th to 5th percentile)

0.984 (0.040, 24.181)

Extreme cold (25th to 1st percentile)

3.369 (0.001, 12163.689)

By angina (having angina):

Moderate heat (75th to 95th Percentile)

4.837 (0.007, 3.430144e+03)

Extreme heat (75th to 99th percentile)

20.664 (0.000, 1.547962e+07)

Moderate cold (25th to 5th percentile)

0.002 (0.000, 5.889127e+03)

Extreme cold (25th to 1st percentile)

0.000 (0.000, 1.066858e+09)

By green space in neighborhood (having green space in neighborhood)

Moderate heat (75th to 95th Percentile)

1.840(0.368, 9.195)

Extreme heat (75th to 99th percentile)

3.306(0.140,78.157)

Moderate cold (25th to 5th percentile)

0.903 (0.368, 2.220)

Extreme cold (25th to 1st percentile)

3.306 (0.140, 78.157)

<u>By publicly accessible green spaces (having publicly accessible green spaces)</u>

Moderate heat (75th to 95th Percentile)

1.553(0.354, 6.814)

Extreme heat (75th to 99th percentile)

2.612(0.144, 47.226)

Moderate cold (25th to 5th percentile)

0.845 (0.363, 1.967)

Extreme cold (25th to 1st percentile)

0.934 (0.081, 10.746)

7 Discussion

7.1 Effect of non-optimum temperature on cardiovascular disease morbidity

Establishing the relationship between non-optimum temperatures and cardiovascular hospital admissions has been challenging. Numerous studies have investigated the association of heat and heatwaves with total and cause-specific cardiovascular hospital admissions. However, the results have been inconsistent and vary geographically (Li et al., 2015). The studies on the association of low temperatures with cardiovascular morbidity have also exhibited mixed results (Bunker et al., 2016; Rica Martínez-Solanas & Basagañaid, 2019). Therefore, it is paramount to investigate the association of low and high ambient temperatures with cardiovascular hospitalizations in different climates and narrower diagnostic groups.

Our study results (study 1) revealed that exposure to high temperatures or heatwaves was not associated with an increased risk of total cardiovascular disease admissions. These findings align with a systematic review by Turner et al. in which no association was observed between daily temperature and total cardiovascular admissions (Turner et al., 2012). Another meta-analysis by Phung et al. found short-term effect of heatwaves on cardiovascular admissions. However, the association between daily temperature and cardiovascular hospitalizations was inconsistent across different studies (Phung et al., 2016). The differences in reported results across various studies might be because of different exposure and outcome indicators. One possible explanation for not finding any association between high temperatures and cardiovascular morbidity could be that patients with acute cardiovascular conditions might die before reaching the hospital for treatment (Michelozzi et al., 2012). This is also explained by the high overall effect of heatwaves on cardiovascular mortality rather than morbidity (Bunker et al., 2016; Moghadamnia et al., 2017). Another study by Kollanus et al. (2021) also reported a positive association of heatwaves with cardiovascular mortality in Finland (Kollanus et al., 2021b).

The scientific literature on the association of cold exposure with cardiovascular hospital admissions has also reported inconsistent results. Our study (study 2) found no association between low temperature and cold spells with total cardiovascular admissions. Likewise, a meta-analysis reported no association of cardiovascular morbidity with low temperatures (Bunker et al., 2016). However, a study from Spain found that cold exposure increased cardiovascular hospital admissions in warmer regions (Rica Martínez-Solanas & Basagañaid, 2019). Likewise, a study from China also reported that cold spells were associated with increased cardiovascular hospital admissions (J. Han et al., 2017). In study 2, we also used windchill (the degree of the cold as received by the human body, which gets worse at high speed) as an exposure variable to evaluate if it predicts cold-associated health effects better than temperature alone. However, we did not find any such evidence. A study from Scotland found a little evidence that windchill was a better predictor of mortality than dry bulb temperature. (Carder et al., 2005). There have been limited studies that investigated the association of wind chill with cardiorespiratory mortality or morbidity. A study from the Netherlands reported that daily variation in cardiovascular mortality was associated with wind chill, as calculated by the Steadman index (Kunst et al., 1994). Another study from the UK found that stroke admissions had a strong relation with wind chill, as calculated by Siple-Passel formula (Gill et al., 1988). There are two main formulas to calculate wind chill, i.e., the Siple-Passel formula and the Steadman formula. The differences in results between different studies could be because of the use of different windchill formulas.

The association of high and low ambient temperatures can vary with specific subtypes of cardiovascular diseases. We found in the study (study 1) that exposure to heatwaves can increase the risk of myocardial infarction admissions in the 65-74 years age group. On the contrary, a study by

Wichmann et al. found no association between apparent temperature (“feels like” temperature to the human body when relative humidity is combined with air temperature) and acute myocardial infarction (AMI) admissions in Copenhagen, Denmark (Wichmann et al., 2012). Likewise, another study from England and Wales did not find an increased risk of myocardial infarction at high temperatures (Bhaskaran et al., 2010). Our study also found signs of increased cerebrovascular admissions in all-ages. However, an overview of the previously published reviews study did not report any association of heat exposure with cerebrovascular morbidity (Song et al., 2017). We also observed a protective association of arrhythmia hospitalizations with heatwaves. A study from Canada did not find any association between heatwaves and arrhythmia (Bai et al., 2016). However, a metareview reported that a 1-degree Celsius increase from the reference temperature elevates the risk of arrhythmia-related morbidity (Liu et al., 2022).

One of the possible reasons for heterogeneity in results could be because no standard definition of heat exposure or heatwaves is available. For example, a study in Rome defined heatwaves as two or more days exceeding the 95th percentile of maximum apparent temperature, while another study from China defined heatwaves as three or more days reaching above 35 degrees Celsius in China (Jun et al., 2008). In our study (study 1), we defined heatwaves using 90th and 95th percentile cutoff points for mean daily temperature. At the 90th percentile cutoff point, heatwaves were defined as temperatures exceeding the percentile for at least four days. For the 95th percentile cutoff point, heatwave length was three or more days. The heterogeneous definitions of heatwaves used in different studies make it difficult to estimate their pooled effects on human health.

Likewise, the association of cold temperatures with cardiovascular morbidity also varies depending on the type of cardiovascular disease. We found (study 2) that exposure to low temperatures increases the risk of myocardial infarction admissions. Our results align with some previous studies. A study from England and Wales reported the positive association of low temperatures with myocardial infarction (Bhaskaran et al., 2010). Likewise, another study from Beijing, China also found that low temperature increases the risk of myocardial infarction admissions (Liu et al., 2018). However, the disease burden of myocardial infarction admissions is lower in cold climatic countries than in countries with warmer climatic conditions (Barnett et al., 2005; Wolf et al., 2009). People in colder climates usually acclimate to extremely low temperatures (Kaciuba-uścilko & Greenleaf, 1989). Therefore, people living in geographical areas with usually warmer temperatures are more vulnerable to cold exposure.

7.2 Effect of non-optimum temperature on respiratory disease morbidity

Exposure to high temperatures and heatwaves can increase the risk of respiratory disease morbidity. In our study (study 1), daily mean temperature during summer months showed a protective association with total respiratory diseases and pneumonia admissions. Contrariwise, some previous studies found that daily mean temperature during summer months can increase the risk of respiratory disease admissions. For example, A study by Michelozzi et al. reported an increase in total respiratory hospital admissions for 12 European cities on exposure to high temperatures (Michelozzi et al., 2012). Another study by Levy et al. from nine California counties found that daily mean temperature increases the risk of pneumonia admissions. However, the Levy et al. suggested that a single hot day affects morbidity in a limited way, but the effect cumulates after continued hot weather (Levy et al., 2015). Our study results revealed that heatwaves pose a risk for total respiratory disease hospital admissions. We (study 1) found that long and intense heatwaves increase the risk of respiratory morbidity in elderly people (≥ 75 years). These results are in line with some previous studies. A study by Mastrangelo et al. found that heatwaves increase total respiratory disease morbidity in people above 75 years of age (Mastrangelo et al., 2007).

A time series analysis from London also showed that heatwaves could increase the risk of emergency room hospital admissions for total respiratory diseases in elderly people (Kovats et al., 2004). A meta-analysis by Xu et al. on heat-associated mortality reported that the intensity of heatwaves is more critical than the duration (Xu et al., 2016). However, as explained, the adverse effects of heat begin at lower temperatures in colder climates. Therefore, policymakers should emphasize local conditions while creating national heat activation plans.

In our study (study 2), we found that exposure to low temperatures causes an increase in respiratory hospitalizations for elderly people above 75 years of age. A meta-analysis also found that low temperatures increase the risk of respiratory hospitalizations in elderly people (Bunker et al., 2016). A possible explanation could be that elderly people are usually more susceptible to the effects of extreme temperatures, which could justify the increased risk of low temperatures with respiratory morbidity in our study. However, there is a need for further research to investigate the etiological mechanisms that cause adverse respiratory symptoms in elderly people.

Extreme ambient temperatures can also have an added effect on health outcomes. This refers to additional health risks if the extreme temperatures are sustained for several consecutive days. The added effect of the cold period is investigated to assess if the effect of low temperatures is stronger during cold spells than isolated days of cold (Gasparrini & Armstrong, 2011). Our study revealed that sustained periods of extremely cold days (added effect of cold spells) increase the risk of asthma admissions in people above 75 years of age. Previous studies have not comprehensively investigated cold spells' main and added effects. A study from China reported no added effect of cold spells on respiratory morbidity (Song et al., 2018). However, some previous studies investigated the main effect of cold spells on asthma morbidity. Two studies from China found an increased risk of asthma morbidity with cold spells in children (Guo et al., 2012; X. Liu et al., 2021). Another study from New York reported an increase in asthma admissions during or after cold spells for all age groups (Fitzgerald et al., 2014). The difference in effect estimates along different studies could be related to climatic differences in diverse geographical areas, discrepancies in adapting behaviors, study populations, exposure definitions, statistical methods, and confounding factors used in the models. However, there is still a need for extensive multi-country studies to properly investigate the main and added effect of low temperatures and cold spells on health outcomes.

The duration and intensity of extreme temperatures are important factors in temperature-associated health effects. A study from 9 European cities reported a two-fold higher effect of longer and more intense heatwaves in northern continental and Mediterranean regions (D’Ippoliti et al., 2010). Another study from China reported that effect of cold temperatures was mainly due to the intensity of cold rather than the duration of cold days (Zhou et al., 2014). Interestingly, contrary to cold intensity or duration, another study's findings revealed that cold waves earlier in the cold season could exhibit more risk, like heatwaves earlier in the warm season (Barnett et al., 2012). This phenomenon may be attributed to the lack of preparedness for early-season cold or heat among individuals. However, acclimatization to temperature variations can act as a protective factor, potentially reducing associated health risks.

7.3 Effect of non-optimum temperature on self-perceived health of individuals

There are two ways to study the effect of weather on human health i.e. 1) investigating the statistical association between weather factors and physiological and pathological factors, and 2) surveys. Weather sensitivity can be regarded as reaction of human body to ongoing weather conditions and especially to changes in weather. Since the weather sensitivity of a population does not appear in medical statistics, therefore, could only be evaluated through survey studies (Bucher & Haase, 1993). Subjective health measures have been extensively used and cover all aspects of health and wellbeing, i.e., biological, social, and mental health of individuals (K. Yang, 2022). Health Related Quality of Life (HRQOL) is a multidimensional concept that assesses subjective health and well-being of individuals. In our study (study 3), we investigated HRQOL using EuroQol Five dimensions questionnaire (EQ-5D) (Rabin & De Charro, 2001). This questionnaire includes five dimensions about mental and physical health status. Additionally, self-rated health (SRH) and comparative self-rated health (CSRH) were investigated. With changing weather conditions, it is expected that low and high ambient temperatures might be associated with poor self-perceived health status of individuals.

In our study (study 3), we found that non-optimum temperatures are not associated with health-related quality of life or self-rated health of individuals. Interestingly, a study from China found that exposure to high temperatures and temperature fluctuations decreases self-rated health. The self-rated health score was based on three different questions asked during survey about health and well-being (Yang et al., 2022). It has also been found in previous research studies that high ambient temperatures during summertime are correlated with indoor temperatures (Nguyen et al., 2014; Zuurbier et al., 2021). Existing studies on the association of indoor temperatures with subjective health found that exposure to high indoor temperatures adversely affects self-rated health. These studies also defined self-rated health based on health and wellbeing questionnaires asked during survey (Li et al., 2020; Sutton-Klein et al., 2021). The adverse effects of extreme temperatures on human health may vary depending on underlying disease conditions. A plausible explanation for not finding any adverse effect of non-optimum temperatures in our study could be that the study subjects were generally in good health, with only a few participants having preexisting chronic diseases.

Our study (study 3) also reported a protective effect of moderate and extreme cold with self-perceived usual activities. This suggests that despite experiencing moderate to extremely cold temperatures, participants reported that they had even less problems in usual activities than normally. However, some other studies reported that non-optimum temperatures can cause a long time to finish a usual task or decrease work performance. (Berglund et al., 1990; Niemelä et al., 2002). There could be several possibilities that participants in our study find it easy to do usual activities in cold weather. We don’t have any obvious explanation for that finding. Nevertheless, there is a need for further studies to understand better the effect of non-optimal temperatures on usual activities in different regions of the world.

Non-optimal temperatures have been suspected to be associated with specific sub-types of mental and behavioral disorders (McMichael et al., 2006). However, our study (study 3) found no association of non-optimal temperatures with depression or anxiety as measured within EQ-5D. Previous studies have shown that ambient temperatures can cause the onset or exacerbation of depression (Wang et al., 2014; Zhang et al., 2020). However, the results from previous studies have been inconsistent. A study from China reported that low ambient temperatures had a more significant effect on depression than high temperatures (Zhang et al., 2020). Another study from Spain found that high temperatures increase the risk of depression (Henríquez-Sánchez et al., 2014). One possible reason for not finding any association between temperature and depression in our study could be that most participants were in good health. People with good health can handle stressful situations effectively and may not be at risk of depression. Another alternative explanation for not detecting an association of self-perceived health measures with low or high temperatures could be that the exposures were insufficient, either in their intensity or duration, to significantly impact the rating of self-perceived health.

7.4 Methodological Considerations in Temperature-related Morbidity Research

Epidemiological studies on temperature-associated morbidity have reported varying results. The health effects of temperature have been investigated using varied study designs, which could be a potential reason for inconsistent results (Ye et al., 2012). The use of different exposure measures and varying definitions for heatwaves could also cause a discrepancy in reported results. Most of the studies have used daily mean temperature as an exposure variable (Kovats et al., 2004; Liang et al., 2008; Schwartz et al., 2004). However, some studies also used minimum (Ebi et al., 2004; Linares & Díaz, 2008) and maximum temperature (Linares & Díaz, 2008; X. Y. Wang et al., 2009) as exposure variables. Besides this, some other studies have also used biometeorological indices such as apparent temperature (R. S. Green et al., n.d.; Michelozzi et al., 2009) or humidex (Mastrangelo et al., 2007). These indices combine air temperature and humidity and estimate the perceived effect of temperature on the human body (Barnett et al., 2010). Along with these, UTCI (Universal thermal climate index) and PET (Physiologically Equivalent temperature) are also commonly used. Both UTCI and PET are based on human energy balance and calculated by using four meteorological variables i.e. temperature, humidity, wind, and solar radiation. A study from Finland investigated the association of relative mortality to physiologically equivalent temperature and air temperature. They reported that temperature alone can give results that are good enough for temperature-associated mortality studies (Ruuhela et al., 2017). There is still a need for further multi-country studies using a consistent methodology to make it easier to compare and interpret the temperature-associated morbidity effects.

7.5 Strengths and limitations of the present study

The present study has several strengths. Annual mean temperature is projected to increase in Finland more than the global average temperature (Ruosteenoja & Jylhä, 2021). Study 1 and Study 2 investigated the effects of non-optimum temperatures in Finland, a northern climate country, significantly adding knowledge to the existing body of literature which could help in developing prevention plans. Moreover, study 1 and study 2 used long time series data practically capturing a hundred percent of hospital admissions, providing a reliable estimation of effects at a population level. The results from comprehensive data allow policymakers and health professionals to make well-informed decisions and better understand trends and patterns. This also helps to identify and target interventions for vulnerable population groups.

Study 1 and Study 2 investigated cause-specific diagnoses within different age groups rather than broad disease categories in the general population. Examining cause-specific diagnosis helps to understand how temperature is associated with specific health conditions. This can give better insights into mechanisms causing temperature related health effects. Also, exploring associations among different age groups helps to get insights into how specific population groups are impacted. If the data is aggregated into broad disease categories or total population, important trends and variations can be missed. Furthermore, in study 3, we investigated the association of temperature with self-rated health using many types of personal information as potential confounding factors such as socioeconomic status, living with a partner, history of chronic diseases etc. The use of personal information enhances the precision of analyses by considering all confounding variables that can distort the true association.

The present study has some limitations as well. Study 1 and Study 2 investigated the association of temperature with only cardiovascular and respiratory hospital admissions. However, exposure to non-optimum temperatures is known to affect other disease categories. Another limitation is that the analyses were restricted to winter or summer months, which might have influenced the results. Previous epidemiological studies have reported the strongest associations between temperature and health outcomes during seasonal transitions when individuals are unaccustomed to shifts in temperature. Moreover, age-specific analyses were not performed for people younger than 18 years of age in Study 1 and Study 2 because of the limited number of cases in that age group. Excluding this information has resulted in a lack of understanding of the health effects of non-optimum temperatures on children and adolescents. In study 3, personal level factors were considered, but information was collected at a single time point only. Therefore, causal relationships cannot be concluded in study 3. Self-perceived health is a comprehensive and inclusive concept that can be affected by a wide range of variables. There could be a possibility that all influencing variables might not have been controlled for as confounding factors. Moreover, the results of this doctoral study project can be generalized to geographical areas with similar climatic conditions. Also, individual persons with certain vulnerabilities could apply the produced information for their improved self-care. However, caution should be taken when generalizing the results because associations between temperature and health outcomes could vary greatly depending on geographical area.

7.6 Conclusions

The main conclusions from our present study are:

- Single days with high temperatures during summer months pose less health risks than heatwaves concerning cardiovascular and respiratory admissions in the Northern climate. However, exposure to heatwaves can increase the risk of hospitalization for pneumonia, total respiratory diseases, COPD, cerebrovascular, and MI.
- Heatwaves associated morbidity may vary depending on the duration and intensity of the hot period and can affect people from all age groups.
- Low winter temperatures can increase the risk of hospitalizations for MI, total respiratory diseases, and COPD. Cold spells can increase the risk of asthma hospitalizations.
- Non-optimum temperatures were not associated with self-perceived health in our study population.

Short-term exposure to non-optimum temperatures can cause adverse health effects among individuals across all age groups, not just among the elderly. Public health officials should make prevention plans based on scientific evidence available. Awareness campaigns should be organized to provide people with an understanding of the impacts of non-optimum temperatures on human health. Given the limited amount of scientific evidence available, there is still a need for further studies investigating the effects of high and low temperatures on morbidity outcomes in various geographical areas.

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HASAN BIN SOHAIL

The topic of my doctoral research is epidemiological studies on the adverse health effects of non optimum ambient temperatures. Non optimum ambient temperatures are among the ten leading causes of death worldwide. The scientific evidence on the effects of non optimum temperatures on morbidity is still scarce and requires further investigation. The author of this dissertation believes in the statement by Thomas Edison : ”Our greatest weakness lies in giving up. The most certain way to succeed is always to try just one more time ”.

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