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Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections☆

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Summary
Objective: The association between cold exposure and acute respiratory tract infections (RTIs) has remained unclear. The study examined whether the development of RTIs is potentiated by cold exposure and lowered humidity in a northern population.
Methods: A population study where diagnosed RTI episodes, outdoor temperature and humidity among conscripts ($n = 892$) were analysed.
Results: Altogether 643 RTI episodes were diagnosed during the follow-up period. Five hundred and ninety-five episodes were upper (URTI) and 87 lower (LRTI) RTIs. The mean average daily temperature preceding any RTIs was -3.7 ± 10.6; for URTI and LRTI they were -4.1 ± 10.6 °C and -1.1 ± 10.0 °C, respectively. Temperature was associated with common cold ($p = 0.017$), pharyngitis ($p = 0.011$) and LRTI ($p = 0.048$). Absolute humidity was associated with URTI

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($p < 0.001$). A 1 °C decrease in temperature increased the estimated risk for URTI by 4.3% ($p < 0.0001$), for common cold by 2.1% ($p = 0.004$), for pharyngitis by 2.8% ($p = 0.019$) and for LRTI by 2.1% ($p = 0.039$). A decrease of 1 g/m^{-3} in absolute humidity increased the estimated risk for URTI by 10.0% ($p < 0.001$) and for pharyngitis by 10.8% ($p = 0.023$). The average outdoor temperature decreased during the preceding three days of the onset of any RTIs, URTI, LRTI or common cold. The temperature for the preceding 14 days also showed a linear decrease for any RTI, URTI or common cold. Absolute humidity decreased linearly during the preceding three days before the onset of common cold, and during the preceding 14 days for all RTIs, common cold and LRTI.
Conclusions: Cold temperature and low humidity were associated with increased occurrence of RTIs, and a decrease in temperature and humidity preceded the onset of the infections.

Introduction

Respiratory tract infections (RTIs) are the most common infections worldwide, and a source of significant morbidity and a considerable economic burden to health care. Seasonal variation in the outbreaks of viral infections is a common phenomenon, with peaks often being observed during the winter months.[1] The reasons for the higher incidence of RTIs in winter have remained controversial, and several causal factors such as changes in host physiological susceptibility, immune function, behaviour (e.g. crowding), and climatic factors (temperature, relative humidity) have been suggested in this context.[2] It is also possible that cold temperatures per se could account for the increased susceptibility of RTIs.

The clinical evidence supporting an association between cold weather and RTIs is based on observations where lowered environmental temperature increases general practitioner (GP) consultations.[3–5] RTIs substantially increase wintertime morbidity[3] and account for at least 20% of the excess winter mortality.[6–8] Experimental evidence, on the other hand, has shown that acute chilling elicits symptoms of common cold.[9] In addition, a recent experimental study with an animal model demonstrated that cold temperatures and low relative humidity are favourable to the spread of influenza.[10]

There are several suggested pathophysiological mechanisms to explain how cold exposure could increase the occurrence of RTIs. Although surrounded by controversy, the available laboratory and clinical evidence suggests that either inhalation of cold air, cooling of the body surface or cold stress causes pathophysiological responses that may contribute to increased susceptibility to respiratory infections.[1,11–14] Although controversial,[15] cold stress could also alter the immune system and affect the susceptibility to RTIs.[16]

The association between cold weather and RTIs in population studies is unclear. Furthermore, no previous studies examining this potential connection have been performed in cold climates. The objective of the present study was to examine the association between the occurrence of respiratory tract infections, outdoor temperature and humidity. For this purpose, a population study consisting of young conscripts performing their military training was conducted. The study combined clinical findings with temperature and humidity measurements.

Methods

Study subjects

The study population included 892 military recruits, 224 asthmatic and 668 non-asthmatic men, from two intake groups enrolled in military service in July 2004 and in January 2005 in the Kajaani garrison in northern Finland. The total number of men in the intake group was 1836 in July 2004 and 1861 in January. All men with a previous diagnosis of asthma according to the data on the previous health and call-up examinations as well as randomly chosen non-asthmatic men were recruited to participate in the study. The voluntary participation rate was 82% in July and 75% in January. The respondents' ages ranged from 17.4 to 29.6 years (Table 1). Both intake groups served part of their military training during the cold season. The service time was 180, 270 or 362 days, depending on the type of training. The study protocol is described elsewhere in more detail.[17] The study protocol was approved by the Medical Ethics Committee of Kainuu Central Hospital, and written informed consent was obtained.

Occurrence of respiratory infections

The conscripts who sought medical attention for acute respiratory tract disease in the military primary care clinic in Kainuu Brigade were assessed initially by a nurse and examined by a physician for diagnosis and treatment if necessary. If a physician was consulted for a respiratory tract infection or exacerbation of asthma, the episode was included in our data. Consultations occurring within two weeks were considered as one episode from which symptoms, findings and drug prescriptions were collected. Respiratory tract infections were diagnosed as common cold, otitis, pharyngitis, sinusitis, bronchitis and pneumonia. In our analyses we grouped the infections further into upper respiratory tract infections (URTIs) including common cold, otitis, pharyngitis and sinusitis and lower respiratory tract infections (LRTIs) including bronchitis and pneumonia.

Temperature and humidity

The meteorological data were obtained from one of the national meteorological stations of the Finnish

Table 1 Characteristics of the conscripts included in the analysis

	All ($n = 892$)	July 2004 ($n = 420$)	January 2005 ($n = 472$)	p-value[a]
Age years' mean (SD)	19.6 (0.8)	19.6 (0.9)	19.6 (0.6)	0.834
Asthma, n (%)	224 (25.1)	116 (27.6)	108 (22.9)	0.103
Atopy,[b] n (%)	455/882 (51.4)	223/416 (53.6)	232/469 (49.5)	0.219
Current smoker,[c] n (%)	378/877 (43.1)	161/414 (38.9)	217/463 (46.9)	0.017
Pack-years of smoking median (range)	2.5 (0.1—15.8)	2.5 (0.2—15.8)	2.3 (0.1—9.0)	0.051
BMI[d]	21.8 (3.8)	22.0 (3.7)	21.6 (3.8)	0.056
Education[e]	90.9 (758)	89.9 (357)	91.8 (401)	0.357

[a] Chi-square or Fisher's exact test for categorical variables, student's t-test or Mann—Whitney U-test for continuous variables.
[b] Knowledge of atopy missing for four subjects in July 2004 and for three subjects in January 2005.
[c] Smoking status missing for six subjects in July 2004 and for nine subjects in January 2005.
[d] BMI missing for one subject in July 2004.
[e] Further education after comprehensive school, education data missing for 23 subjects in July and for 35 subjects in January 2005.

Meteorological Institute (Kajaani Airport Meteorological Station, 64°N, 27°E) located ca. 15 km from the garrison and linked to the data. Means of the average (T_{avg}, °C) and maximal (T_{max}, °C) temperatures of the preceding three days and two weeks of the onset of an infection were calculated and included in the analyses. The maximal temperatures were included because they usually occur during the active phase of the day. In addition, the association between absolute humidity (AH, g/m^{-3}) and RTIs was explored.

The meteorological data of the three preceding days were included because of the time-course of acute rhinovirus infections and development of symptoms of common cold.[18,19] Furthermore, the temperature and humidity in the two weeks preceding the onset of infection were also used in the analyses to include e.g. the biphasic development of bacterial pneumonia.

Statistical analyses

Student's t-test was used to compare age and body mass index between the two intake groups. Comparison of pack-years of smoking was done by Mann—Whitney U-test due to non-normal distribution. Categorical variables were compared by Chi-square tests or Fisher's exact test when appropriate. The Generalized Additive Model (GAM) procedure[20] with the binomial link function and logit link was used to provide a graphic representation of the relationship between RTIs and daily average temperature available in the R software, release 2.50 (R Development Core Team, 2007). The estimated risk by infection type and temperature was analysed by logistic regression analysis. Model fitting was based on the generalized estimating equation (GEE) approach with exchangeable correlation matrix. Temperature trends preceding the infection were analysed by the repeated measures of ANOVA for either a three-day or two-week period. Statistical significance was set at $p < 0.05$.

Results

The association between daily monitored ambient temperature and occurrence of respiratory tract infections was studied among the military conscripts from July 2004 to January 2006. Among the initial examinations for RTI episodes ($n = 720$), a total of 643 respiratory infection episodes were diagnosed. Of these 595 (93%) were URTI (common cold $n = 354$, sinusitis $n = 196$, pharyngitis $n = 99$, otitis $n = 38$) and 87 (14%) LRTI episodes (bronchitis $n = 74$, pneumonia $n = 15$). During the study period the outdoor temperature ranged from −30.7 to +27.9 °C. The occurrence of RTI by temperature (mean of T_{avg},°C and T_{max},°C) and humidity (mean of AH, g/m^{-3}) of the preceding three days of the infection is presented in Table 2. For occurring RTIs there were no statistically significant differences in the average (-4.0 ± 1.4 °C and -2.9 ± 11.0 °C, $p = 0.243$ healthy vs. asthmatic) and maximal (0.0 ± 9.7 °C and 1.0 ± 10.4 °C, $p = 0.251$, healthy vs. asthmatic) temperature or humidity (3.8 ± 2.9 and 4.2 ± 3.3 g/m^{-3}, $p = 0.065$, healthy vs. asthmatic) of the preceding three days between healthy ($n = 440$) and asthmatic ($n = 203$) conscripts.

Table 2 Mean of the average (T_{avg}, °C) and maximum (T_{max}, °C) temperatures and absolute humidity (AH, g/m^{-3}) during the three days preceding the onset of RTI

	T_{avg} (°C)		T_{max} (°C)		AH (g/m^{-3})	
	Mean ± SD (n)	95% CI	Mean ± SD (n)	95% CI	Mean ± SD (n)	95% CI
URTI	−4.1 ± 10.6 (595)	(−5.0; −3.3)	−0.1 ± 9.8 (595)	(−0.9; +0.7)	3.8 ± 3.0 (354)	(3.5; 4.1)
LRTI	−1.1 ± 10.0 (87)	(−3.2; +1.0)	2.9 ± 9.7 (87)	(0.8; +4.9)	4.3 ± 2.9 (87)	(3.7; 4.9)
Common cold	−4.5 ± 10.5 (354)	(−5.6; −3.4)	−0.4 ± 9.7 (354)	(−1.4; +0.6)	3.8 ± 3.0 (354)	(3.5; 4.1)
Any RTI	−3.7 ± 10.6 (643)	(−4.5; −2.8)	0.3 ± 9.9 (643)	(−0.4; +1.1)	3.9 ± 3.0 (643)	(3.7; 4.1)

Temperature

The GAM analysis revealed a significant linear association between temperature and infection type ($n = 718$). The association between temperature and RTIs (common cold and LRTI) is presented in Fig. 1. The average temperature was significantly associated with episodes of common cold ($p = 0.017$), pharyngitis ($p = 0.011$) and LRTI ($p = 0.048$). The association between URTI and temperature was only marginally statistically significant ($p = 0.055$). A 1 °C decrease in temperature increased the estimated risk for URTI by 4.3% (OR 0.96, 95% CI 0.94; 0.97, $p < 0.0001$), for common cold by 2.1% (OR 0.98, 95% CI 0.97; 0.99, $p = 0.004$) and for pharyngitis by 2.8% (OR 0.97, 95% CI 0.95; 0.99, $p = 0.019$). The estimated risk for LRTI for a 1 °C decrease in temperature was 2.1% (OR 1.02, 95% CI 1.0; 1.04, $p = 0.038$).

The average temperature decreased linearly (decrease 1.3–1.4 °C) during the preceding three days before the onset of an infection separately for any RTI ($F = 58.4$, $p < 0.001$), URTI ($F = 56.8$, $p < 0.001$), LRTI ($F = 4.2$, $p = 0.042$) or common cold ($F = 28.0$, $p < 0.001$), being the lowest one day before seeking medical consultation. Furthermore, when examining the temperature trend for the preceding two weeks a significant linear decrease in temperature was observed for all infections ($F = 26.4$, $p < 0.001$), URTI ($F = 17.2$, $p < 0.001$) and common cold ($F = 12.9$, $p < 0.001$), but not for LRTI.

Humidity

According to the generalized additive model, absolute humidity was significantly associated with URTI ($p < 0.001$), but not with LRTI. The association between absolute humidity and common cold was marginally statistically significant ($p = 0.0527$). According to the logistic regression model a decrease of 1 g/m^{-3} in AH increased the estimated risk of URTI by 10.0% (OR 0.9, 95% CI 0.86; 0.96, $p < 0.001$), and separately for pharyngitis by 10.8% (OR 0.9, 95% CI 0.82; 0.99, $p = 0.023$). The estimated risk for common cold increased by 4.8%, but showed only marginal statistical significance (OR 0.95, 95% CI 0.91; 1.0, $p = 0.053$). Absolute humidity did not affect the occurrence of otitis or sinusitis. The association between absolute humidity, common cold and LRTI is presented in Fig. 2.

When examining the levels of absolute humidity during the preceding three days of the infection a significant decrease was observed preceding the onset of common cold (AH 3.8–3.7 g/cm^{-3}, $F = 5.3$, $p = 0.021$), but not the other RTIs. Absolute humidity decreased linearly during the preceding two weeks for all RTIs (AH 4.9–4.3 g/cm^{-3}, $F = 28.1$, $p < 0.001$), common cold (AH 4.4–4.0 g/cm^{-3}, $F = 52.2$, $p = 0.000$) and LRTI (AH from 4.4–4.1 g/cm^{-3}, $F = 10.4$, $p = 0.001$).

Discussion

The novel approach of the present study was to examine the association of daily monitored environmental temperatures and humidity with the onset of respiratory infections in a northern population with a high infection rate. We demonstrated that the occurrence of respiratory tract infections increases in cold temperatures and with lowered humidity. In addition, the onset of respiratory infections was preceded by a drop in temperature and humidity.

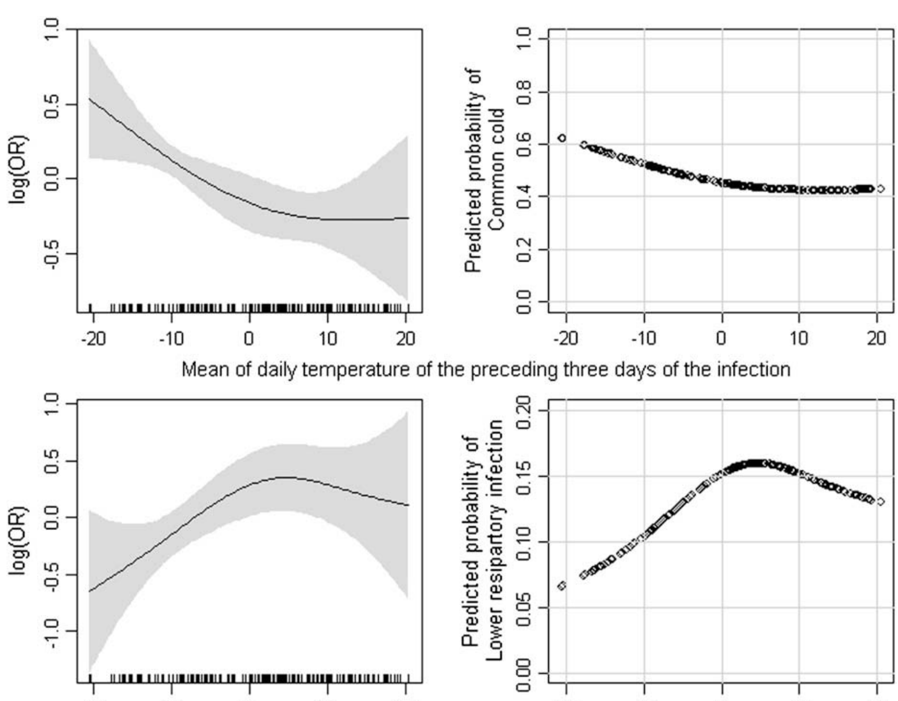

Figure 1 Relative odds (logarithmic scale) on common cold (upper panel) and LRTI (lower panel) by the mean of the average daily temperature of the three days preceding the onset of an infection. The shaded area represents the 95% confidence interval of the relative odds curve. Based on a generalized additive model with binomial error and identity link.

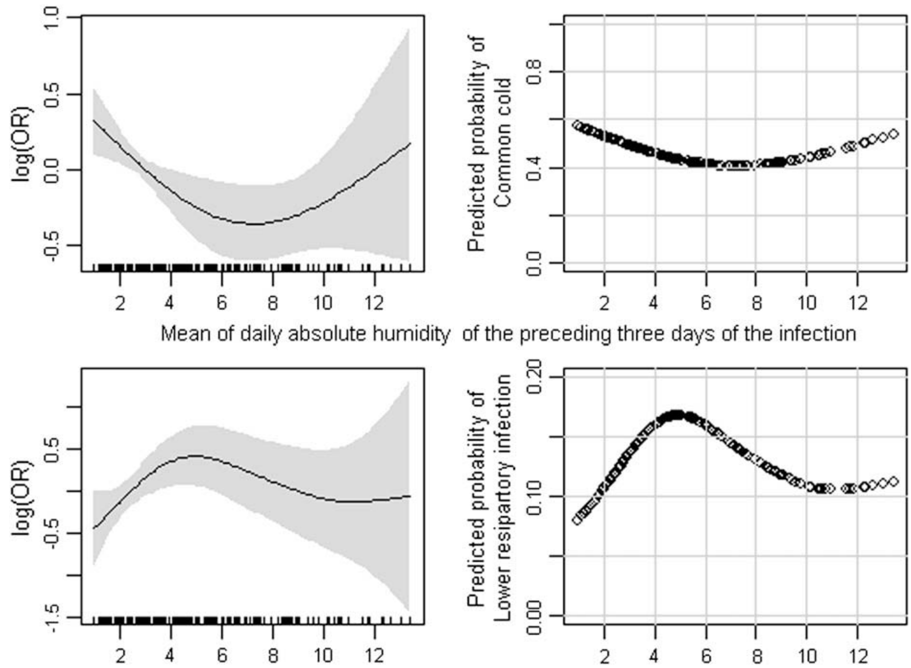

Figure 2 Relative odds (logarithmic scale) on common cold (upper panel) and LRTI (lower panel) by the mean of the absolute humidity (g/m^{-3}) of the three days preceding the onset of an infection.

The most common outdoor temperature range for the onset of a respiratory infection episode was 0 to −5 °C. It should be noted that the temperature range during the follow-up period was wide, including temperatures from −30 to +30 °C. According to our results, daily average temperature was significantly associated with common cold and pharyngitis, which occurred more often in cold temperatures. Aetiologically, viral infections dominate in URTIs, and rhinovirus has been traditionally been considered an upper airway pathogen frequently associated with symptoms of common cold.[18,19] In a cold environment the temperature of the upper airways may be favourable to rhinovirus. Rhinovirus replicates best at airway temperatures of 33–35 °C,[21] which approximates the temperature of the airways.[22]

We also observed that lower humidity was associated with an increased amount of URTIs and that it especially increased the occurrence of pharyngitis. This finding is consistent with a previous study,[4] where the amount of GP consultations increased with lower absolute humidity. One plausible explanation for the association between humidity and RTIs is that some viruses, like the influenza virus, seem to be more stable in cool and dry air.[10,23] A recent experimental animal study showed for the first time that both cold temperature and low humidity favour the spread of the influenza virus.[10] In this study housing animals in the cold prolonged viral growth, and viral transmission was highly efficient with low relative humidity. This suggests that low temperatures and low humidity per se may be contributing factors for RTIs. Similar to common cold, pharyngitis is also considered to be mainly caused by viruses, and it was inversely associated with temperature and low humidity, too. Common cold, primarily a viral infection, can be accompanied by bacterial infections leading to more severe complications, such as LRTI, including pneumonia.

The association between LRTIs and temperature was non-linear and the susceptibility was highest at temperatures between 0 and 10 °C, while the risk decreased with both colder and warmer temperatures. Similarly, as humidity decreased, the occurrence of LRTIs decreased. The different impacts of cold weather on URTI and LRTI can partially be explained by the different cooling patterns of the upper and lower airways in cold weather. Although the long-term responses of cold air inhalation have been shown to extend to the lungs causing inflammation,[24] this has mainly been demonstrated in cases involving heavy physical exercise (and oronasal breathing) when also the lower respiratory tract is more affected by cold. Other reasons for the different effect of cold on LRTI could be the different aetiological pattern and often biphasic nature of the development of LRTI. The episode begins as a mild viral infection, and the outcome, which is not as temperature-sensitive as the primary viral infection, may be predetermined by host factors, such as immunological defence mechanisms and genetic susceptibility.

One finding of the present study was also that the ambient temperature decreased significantly during the three days preceding the onset of an acute respiratory infection (all infections, URTI, LRTI). The decrease in temperature ranged between 1.3 and 1.4 °C. The temperature trend for a longer period also demonstrated a significant decrease (any RTIs, URTI, common cold) of approximately 0.4–1.3 °C. Similarly, we observed that the onset of RTIs was preceded by a reduction in humidity. Especially, a linear decrease in humidity was observed during the two weeks preceding the onset of RTI. The results are in accordance with a previous study conducted in Greece where GP consultations for respiratory tract infections were studied and compared with outdoor temperatures.[4] In their study a 15-day lag between T_{min} and the peak of GP consultation was found; a decrease of 10 °C in T_{min} increased GP consultations by 28%. Consistently with our findings, the study also revealed a three-day lag effect. It has also been shown that a sudden change in temperature (increase or decrease) from the previous day favoured the onset of a new case of acute laryngitis.[25] Similarly, studies on respiratory mortality have demonstrated a 12-day lag after a cold spell.[26]

A few previous studies have demonstrated an association between weather parameters and RTIs. Danielides et al.[25] conducted a retrospective study on medical records and showed that several meteorological parameters (including low temperatures) were associated with increased occurrence of acute laryngitis. However, their study was conducted in a temperate, southern climate (Greece), where the occurrence of subfreezing cold temperatures is not as frequent as in the present study. Similarly, Hajat et al.[3] observed increased numbers of GP consultations, especially for LRTIs, with cold temperatures in the UK, but this study was restricted to elderly people.

The reasons for the seasonality and peak winter incidence of many respiratory pathogens are controversial.[2] There are several proposed mechanisms for the increased occurrence of RTIs during the winter months. Indoor crowding promotes transmission, and likely affected the number of observed RTIs in this study as well. Military trainees are at particularly high risk for infection epidemics due to crowded living conditions, harsh exercise and environmental conditions.[27] It has been suggested that acute cooling of the body surface could elicit a reflex vasoconstriction in the nose and upper airways, which may inhibit the respiratory defence and convert an asymptomatic subclinical viral infection into a symptomatic clinical infection.[12] A recent study examining the effects of acute cooling of the feet showed common cold symptoms in 4–5 days in 10%, suggesting that chilling is in fact associated with the onset of common cold.[9] However, the study did not include any objective evidence, such as virological analyses to support this observation. Breathing cold air causes cooling of the upper respiratory tract[11,28] and subsequent drying of the mucosal membrane.[13] In sensitive individuals the drying of the mucosa may lead to epithelial damage.[14] Furthermore, an in vitro study showed that cooling enhances the norepinephrine response of the nasal mucosa, which could indicate increased vasoconstriction in the upper airways.[29] These effects could depress ciliary movements in the respiratory tract and affect the susceptibility to infections. Previous results on small mammals suggest that acute cold stress could also suppress several cellular and humoral components of the immune system.[16] However, the results concerning the effects of cold exposure on human immune function have shown divergent results.[15] In summary, some of the abovementioned mechanisms and physiological responses may have accounted for the observed increased occurrence of RTIs in the cold. However, these need to be investigated further.

The strengths of this study include the fact that a defined population was followed at high latitude, from where similar results have not been reported previously. The results show an association between low temperature, humidity and occurrence of RTIs, but a direct causality cannot be demonstrated. Additional analyses are needed to minimize the confounding caused by crowding and annually occurring respiratory infection epidemics. Due to the annually occurring winter peaks in RTIs further studies on the association between temperature and infections should be carried out in different brigades at the same time and on repeated occasions to confirm our results. In the future, virological and bacterial analyses may give further information on the association between temperature and microbes. The military environment is optimal for examining the association between cold temperatures and RTIs, because compared with the general population, where cold exposures are usually recurrent but short,[30] conscripts are exposed to cold frequently and for prolonged periods, especially during their outdoor training. Although the population of military conscripts might be considered a selected group, in Finland with mandatory military service, they represent a normal population of young men, and the effects of indoor crowding are similar to those observed in schools and kindergartens in winter.

In conclusion, RTIs occurred most often when the ambient temperature was at or below 0 °C. Average daily temperature was significantly associated with URTI and LRTI episodes and separately for common cold and pharyngitis. A decrease in temperature increased the risk for common cold and pharyngitis. Furthermore, a lower absolute humidity increased the risk of URTI and pharyngitis. The association between temperature, humidity and LRTI was non-linear. The outdoor temperature decreased during the three days and two weeks preceding the onset of an infection. A significant decrease in humidity was also observed during the two weeks preceding the onset of RTI. The results indicate that cold temperatures and low humidity are associated with an increased occurrence of respiratory tract infections and this information is important from a public health perspective when planning appropriate cold risk management strategies.

Conflict of interest statement

The authors declare no conflict of interest.

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