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Effects of weather, air pollution and Oktoberfest on ambulance-transported emergency department admissions in Munich, Germany

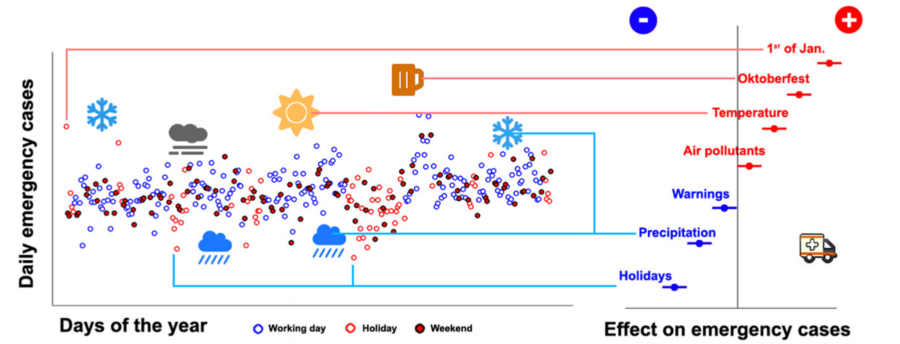
Wael Ghada [a,*], Nicole Estrella [a], Dominik Pfoerringer [b], Karl-Georg Kanz [b,c], Viktoria Bogner-Flatz [c,f], Donna P. Ankerst [a,d], Annette Menzel [a,e]

[a] TUM School of Life Sciences, Technical University of Munich, Freising, Germany
[b] Klinik und Poliklinik für Unfallchirurgie, Klinikum rechts der Isar, Technical University of Munich, Munich, Germany
[c] Emergency Medical Services Authority, Munich, Germany
[d] Department of Mathematics, Technical University of Munich, Garching, Germany
[e] Institute for Advanced Study, Technical University of Munich, Garching, Germany
[f] Department of General, Trauma and Reconstructive Surgery, Ludwig Maximilians University Hospital Munich, Munich, Germany

HIGHLIGHTS

- Medical emergencies peak in Oktoberfest and New Year's Day in the Greater Munich Area.
- Daily ED numbers are modelled by calendar, environmental, and weather warning variables.
- The influence of weather and air pollution differs by season, patients' sex and age.
- Timely allocation of healthcare resources should consider calendar dates, weather and air quality.

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Climate change and increasing risks of extreme weather events affect human health and lead to changes in the emergency department (ED) admissions and the emergency medical services (EMS) operations. For a better allocation of resources in the healthcare system, it is essential to predict ED numbers based on environmental variables. This publication aims to quantify weather, air pollution and calendar-related effects on daily ED admissions.
Methods: Analyses were based on 575,725 admissions from the web-based IVENA system recording all patients in the greater Munich area with pre-hospital emergency care in ambulance operations during 2014–2018. Linear models were used to identify statistically significant associations between daily ED admissions and calendar, meteorological and pollution factors, allowing for lag effects of one to three days. Separate analyses were performed for seasons, with additional subset analyses by sex, age and surgical versus internal department.
Results: ED admissions were exceptionally high during the three-week Oktoberfest, particularly for males and on the weekends, as well as during the New Year holiday. Admissions significantly increased during the years of study, decreased in spring and summer holidays, and were lower on Sundays while higher on Mondays. In the warmer seasons, admissions were significantly associated with higher temperature, adjusting for the effects of sunshine and humidity in all age groups except for the elderly. Adverse weather conditions in non-summer seasons were either linked to increasing ED admissions (from storms, gust) or decreasing them from rain. Mostly,

* Corresponding author at: Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany.
E-mail address: ghada@wzw.tum.de (W. Ghada).

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but not exclusively, in winter, increasing ED admissions were associated with colder minimum temperatures as well as with higher NO and PM_{10} concentrations.
Conclusions: In addition to standard calendar-related factors, incorporating seasonal weather, air pollutant and interactions with patient demographics into resource planning models can improve the daily allocation of resources and staff of EMS operations at hospital and city levels.

1. Background

Overcrowding at hospital emergency departments (ED) delays care times, worsens patient conditions, and consequently leads to higher mortality rates (Salway et al., 2017). Therefore, hospital managers and emergency medical service (EMS) associations aim to reduce related risks due to overcrowding through improved allocation of resources and staff. This requires improved ED visit prediction and understanding of reasons behind visit fluctuation (Marcilio et al., 2013), such as by consideration of subgroups of patients (Pförringer et al., 2018).

ED visits are commonly predicted by a combination of factors related to calendar, weather, and air pollution. Most models of ED visits account for calendar-related variables, such as day of week, month, year, and holiday (Wargon et al., 2010; Boyle et al., 2012; Bolt and Sparks, 2013; Marcilio et al., 2013; Jilani et al., 2019; McAllan et al., 2019; Duwalage et al., 2020). Special holidays, such as New Year's Eve, Christmas and Boxing Day, have been shown to be associated with a higher number of ED visits (Duwalage et al., 2020). Although the role of seasons is not clear, for example see (Marcilio et al., 2013; Castner et al., 2016) versus (McAllan et al., 2019), accounting for long term and seasonal patterns facilitates the detection of short term associations between the ED visits and other environmental conditions of interest (Bhaskaran et al., 2013). However, the effect of calendar variables can be inhomogeneous even within the same city (Wargon et al., 2010). Special attention should be paid to epidemic periods (Wargon et al., 2018), and allergy seasons (Erbas et al., 2012) which may overrule seasonal patterns.

A multitude of weather-related variables has been tested for their influence on ED visits with temperature as the most common. Higher maximum temperatures and heat waves lead to more ED visits (Duwalage et al., 2020) and increase mortality rates, especially among the elderly (Schaffer et al., 2012). The effect of heat appears to be spatially variable within the same city (Hondula and Barnett, 2014). It also varies with the targeted patient group (Vaneckova and Bambrick, 2013). Nonetheless, temperature and other meteorological variables, such as precipitation, wind, humidity and insolation, may fail to improve ED visit prediction despite having a significant influence (Calegari et al., 2016), especially for long-term forecasts (Wargon et al., 2009).

High concentrations of ambient air pollutants, such as $PM_{2.5}$, PM_{10}, NO_2, SO_2 and O_3, increase asthma ED visits globally (Anenberg et al., 2018), especially in urban areas where air pollution sources are abundant (Achakulwisut et al., 2019). The pollution effect on ED visits is higher for children (Ostro et al., 2009) and women (Luginaah et al., 2005). Fine particles have an immediate effect on cardiovascular diseases, and a delayed effect for respiratory diseases (Kim et al., 2012).

The majority of ED visit models proposed in the literature is limited to calendar-related predictors, most likely to simplify practical implementation and use at hospitals. Environmental factors are highly correlated and vary with seasons, bringing challenges of high-dimensionality and multi-collinearity into modeling. However, environmental factors have statistically significant influences on ED visits which should be incorporated rather than disregarded out of inconvenience. Recent climate change has been reported to exhibit manifold direct and ecosystem-mediated impacts on human health, and research to quantify its ultimate impact is ongoing (Smith et al., 2014). Whereas mortality and morbidity related to heat waves and pollutants have been widely studied in Europe (Hertel et al., 2009; Gabriel and Endlicher, 2011; Breitner et al., 2014; Lowe et al., 2015), less information has been conveyed concerning hospital admissions (Ferrari et al., 2012; Shiue et al., 2016). Wang and Lin (2014) reported that ED admissions are most suitable to analyze weather effects, and thus in the long run climate change impacts on specific illnesses and accidents of all kinds. Therefore, projections of climate change mandate the increased need for optimized ED management and resource allocation via comprehensive models incorporating weather and pollution-related variables as drivers (Kingsley et al., 2016).

Towards this end, we collected and analyzed five years of EMS vehicle operations in Munich, Germany to identify the most influential calendar-related variables, meteorological conditions, weather warnings, as well as ambient air pollutants associated with daily ED admissions. We hypothesized that environmental factors influenced daily ED admissions independently from seasonal and calendar impacts, with differences according to age, sex, and ED type.

2. Data and methods

2.1. EMS data

EMS admissions to hospitals in the city and the county district of Munich were provided by the Munich Emergency Services Authority for the period 2014 to 2018. Data were collected through the Interdisciplinary Medical Care Capacity Management System ('Interdisziplinärer Versorgungsnachweis' IVENA), an online web-based system for hospitals to display their current healthcare capacities to the dispatchers of the EMS Command Centre ('Integrierte Leitstelle' ILS) who assign emergency rescue vehicles (first responders, ambulances and helicopters) to receptive hospitals. IVENA guides and directs admissions and aims to reduce unnecessary journeys. The daily ED admissions in this paper do not include the walk in patients. Planned transportations of non-emergency cases were also excluded.

The 5-year daily data comprised 575,725 entries, including day and time of the emergency call, age and sex of each patient as well as initial diagnosis. The list of initial diagnoses and the assigned departments are provided in the supplementary Table S2. In addition to total daily ED admissions, subgroups related to age, sex and assigned department were performed; see Table 1. One week in April 2014, which exhibited an unrealistically small number of patients due to reporting error, was excluded from the analysis (see Fig. 1).

As explanatory calendar variables, we used year, day of the week, public and Bavarian school holidays (Bavarian Ministry of education, 2020) as well as the days of Munich Oktoberfest (16 to 18 days from mid-September till beginning of October). We also considered New Year's Eve and New Year, and the working days of the week following the start or the end of the daylight saving time.

2.2. Environmental data

We obtained data on ambient air pollution as hourly concentrations (μg m^{-3}) of particulate matter (PM) with an aerodynamic diameter < 10 μm (PM_{10}), ozone (O_3), nitrogen monoxide (NO),and nitrogen dioxide (NO_2) (Bavarian State Office for environment, 2020). We downloaded hourly meteorological data from the Climate Data Center of the German Meteorological Service (DWD)

Table 1
Average daily hospital ED admissions through IVENA system (2014–2018) by season as well as by subgroups of patients.

		All periods	Winter	Spring	Summer	Fall
Average daily number of admissions[a]		315.3	313.7	307.8	313.5	326.2
By age	Elderly >70	127.6	134.9	125.6	122.3	127.8
	Adults 18–70	157.7	149.4	152.1	161.3	167.8
	Children <18	26.4	25.6	26.7	26.5	26.8
By sex	Female	156.5	159.3	153.0	155.2	158.7
	Male	156.6	152.1	152.8	156.1	165.2
By assigned department[b]	Surgery	127.0	119.4	123.2	131.0	134.6
	Internal	178.2	184.4	174.9	172.3	181.4

[a] The total number of admissions and the percentages within each category are provided in Table S1.
[b] The numbers of cases within each category are provided in Table S2.

(Deutscher Wetterdienst, 2020) for the years 2014 to 2018 and the weather station #3379 in Munich. We calculated the universal thermal climate index (UTCI) based on air temperature, wind speed, relative air humidity and mean radiant temperature (Bröde et al., 2012). Since the direct and diffuse radiation were not available, we used relative air humidity and the cloud cover to estimate the mean radiant temperature (Matzarakis et al., 2007; Lindauer et al., 2017). Missing values in the meteorological data were identified in less than 4.5% of the period of interest. The missing values were imputed using k-nearest neighbor (k = 5).

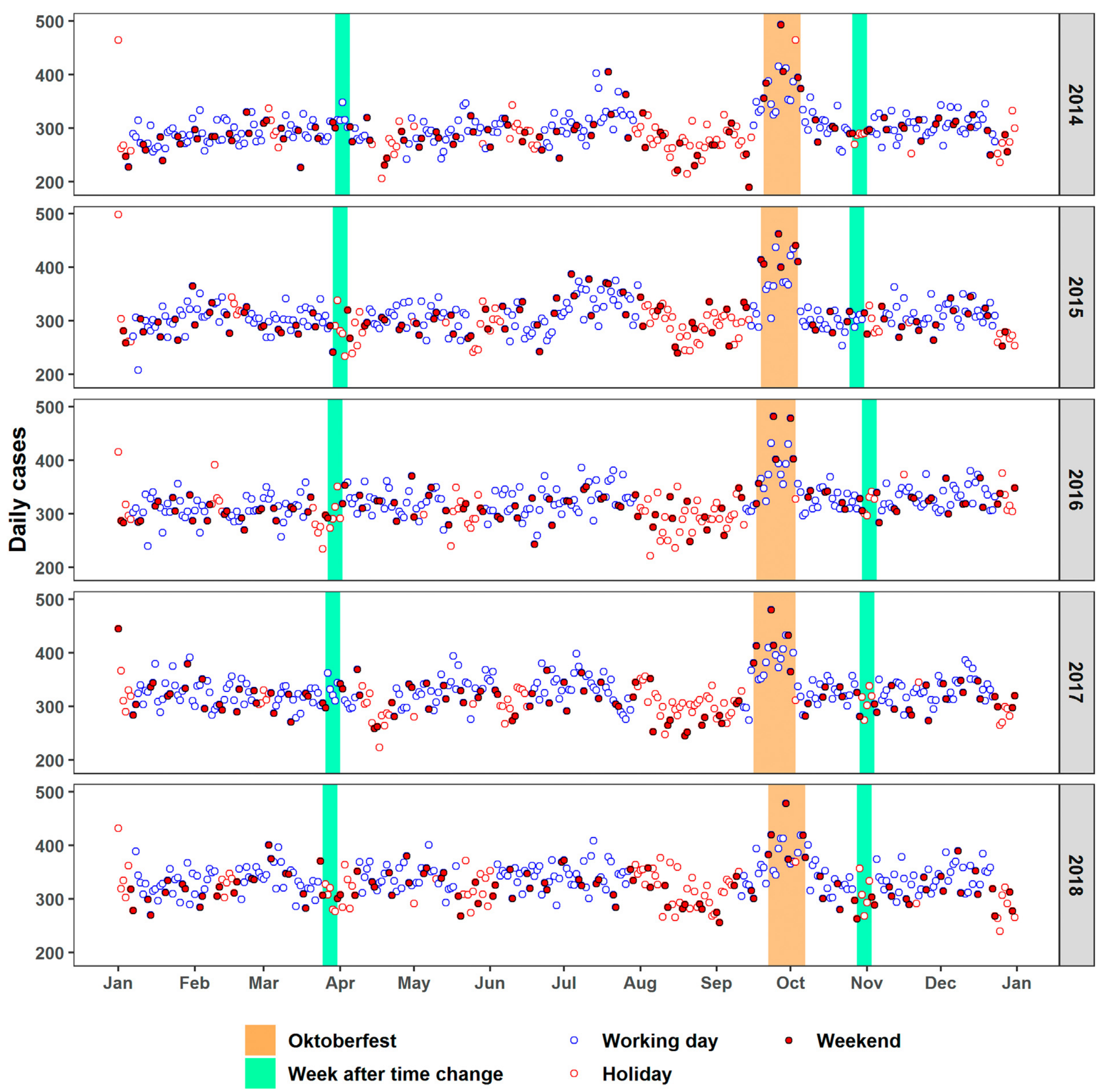

Fig. 1. Daily ED admissions through the IVENA system in the Greater Munich Area (2014–2018).

Table 2
Daily mean concentrations of ambient air pollutants and meteorological factors, Munich, Germany (2014–2018).

	Total period		Winter		Spring		Summer		Fall	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Temperature (°C)	10.89	7.61	2.55	4.14	10.55	5.25	19.71	3.61	10.60	5.18
UTCI (°C)	12.92	10.09	2.33	6.97	12.66	7.66	23.50	4.15	12.96	7.72
Pressure* (hPa)	955.73	7.18	956.02	9.81	953.93	7.20	956.10	3.95	956.90	6.23
* Station height 515 m a.s.l										
Wind (m sec^{-1})	2.74	1.15	2.93	1.45	2.93	1.07	2.58	0.69	2.51	1.18
Cloud cover (%)	66.86	30.05	76.40	26.44	64.11	30.87	57.36	29.99	69.80	29.42
Absolute humidity (g m^{-3})	7.47	2.92	4.59	1.10	6.51	1.98	10.88	1.82	7.83	2.18
Precipitation amount (mm)	2.47	5.59	1.83	3.68	2.29	4.87	3.40	7.20	2.36	5.86
Precipitation duration (hours)	2.75	4.36	3.09	4.38	2.77	4.50	2.44	3.78	2.70	4.72
Sunshine duration (hours)	5.10	4.53	2.58	2.99	5.90	4.54	7.88	4.68	3.97	3.79
PM_{10} (μg m^{-3})	20.67	15.52	24.10	26.97	21.05	11.04	17.83	6.10	19.75	8.12
O_3 (μg m^{-3})	41.96	22.43	26.68	17.15	52.30	15.59	62.02	15.88	26.39	15.47
NO (μg m^{-3})	36.66	24.55	49.02	34.18	29.94	14.70	24.37	9.51	43.64	23.59
NO_2 (μg m^{-3})	42.57	12.36	46.54	15.51	42.59	11.99	39.71	9.70	41.49	10.51

We aggregated all hourly values into daily values using the mean, minimum, maximum, duration, and summation when appropriate. In order to study lag effects, we also aggregated these factors for one-, two-, and three-days. A summary of the meteorological and ambient pollution data is provided in Table 2. The correlation matrix of the main environmental variables is provided in Fig. 2, and for each season in Fig. S4.

DWD provided hourly weather warnings announced in Munich during the same period. The durations of these warnings in hours were considered as possible explanatory variables; see Table 3.

2.3. Statistical methods

Normal linear models were used to predict daily ED admissions, with the quantity linearly dependent upon calendar and meteorological variables, pollution concentrations, weather conditions and warnings. Lag effects of meteorological and pollution variables from one to three days were all considered as potential predictors in the models. A complete enumeration of the 222 predictor features is provided in Supplementary Table S2. Optimal selection of the final set of predictors to include in models was performed in two steps. The first step included minimization of the Bayesian Information Criterion (BIC) for models fit to data spanning the four meteorological years from January 2014 to November 2017. The second step comprised cross-validation minimizing the Root-Mean-Square-Error (RMSE) from candidate models constructed from the first step and evaluated on data from the meteorological year 2018 (December 2017–November 2018) as the test set.

Separate prediction model analyses were performed for the meteorological seasons (DJF winter, MAM spring, JJA summer, SON fall), with additional subset analyses for the elderly (70 year +), adults

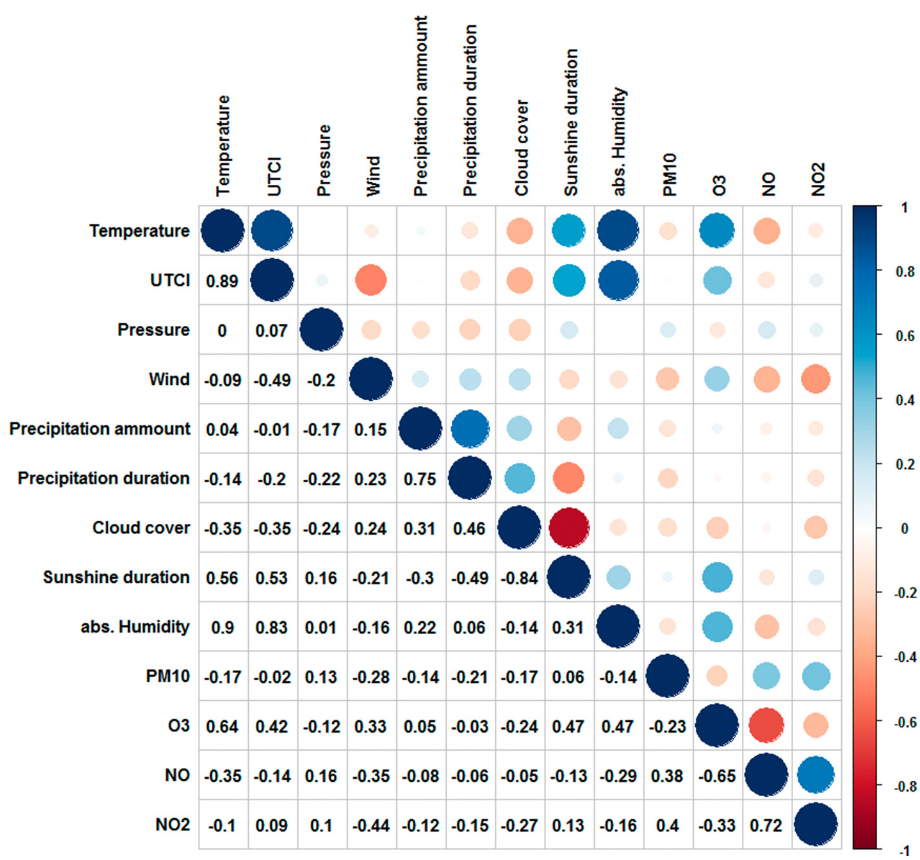

Fig. 2. Correlations between the main environmental variables.

Table 3
Number of days[a] with special weather conditions and warnings, Munich, Germany (2014–2018).

		Total period	Winter	Spring	Summer	Fall
Conditions	Snow	99	63	15	9	12
	Fog	414	128	48	41	197
	Thunderstorm	156	5	41	98	12
	Storm Beaufort ≥ 6	196	79	47	33	37
	Storm Beaufort ≥ 8	10	5	2	0	3
	Glaze/clear ice	10	9	0	0	1
	Rime	112	56	47	0	9
	Hail	8	0	2	6	0
	Rain	859	220	213	229	197
Warnings	Frost	565	363	128	0	74
	Thunderstorm	328	12	84	198	34
	Slipperiness	336	246	53	0	37
	Snow	164	112	33	0	19
	Fog	171	68	8	2	93
	Gusts	282	110	58	51	63
	Heavy rain	60	0	6	42	12
	Long lasting rain	62	2	15	21	24
	Hail	23	0	2	18	3

[a] These include any day when the condition/warning was observed/issued for at least 1 h.

(18–70 year), children, females, males, surgical and internal cases. This comprises a total of 32 models which are presented in terms of the change in total daily ED admissions associated with a unit increase in each of the associated factors. For example, an increase in the mean temperature by 1 °C causes an increase of the total daily ED admissions in summer by 4.37 (see Fig. 3).

Model diagnostics revealed no autocorrelation in the residuals so that independent normal errors could be assumed. Similar checks revealed that the Poisson distribution as regularly used for counts did not improve the goodness-of-fit, ostensibly due to large sample sizes fulfilling the Normal distribution approximation. The variance inflation factor values were mostly below 2 indicating low multicollinearity in the final models.

All computations were performed in the R statistical software package (version 3.5.1) and all comparisons were made at the two-sided 0.05 level of significance.

3. Results

3.1. Daily total ED admissions

Daily numbers of ED admissions increased linearly over the time period of the study, 2014–2018, on average by 5.5, 6.4, 11.9 and 11.87 per year for summer, fall, winter and spring, respectively (Fig. 3). They declined on Sundays in winter, spring and summer (−11.2, −12.5 and −16.9, respectively), on Wednesdays in winter (−14.2), and increased on Mondays (+12.7) in winter as well as on Saturdays (+15.9) and Fridays (+10) in fall. The Oktoberfest was associated with a sharp increase of 77.9 more patients per day in the fall, while the time changes in the fall and spring did not result in statistically significant changes in visits after adjustment for other factors. On the other hand, public holidays and school vacations in all seasons were associated with smaller patient numbers (spring −28.4, summer −30.2, fall −12.3 and winter −11.7).

Higher levels of select single air pollutants increased ED daily admissions in winter, fall and summer, but not in the spring. Specifically, in winter a unit-increase in the current day maximum PM_{10} was associated with 0.2 more daily visits, in fall a unit-increase in the current day minimum O_3 concentration was associated with a 0.5 increase in ED admissions, and in summer a unit-increase in mean NO concentration over the last three days was associated with 0.3 more daily visits.

Multiple weather features impacted daily ED admissions for all seasons, except winter. In summer, ED daily admissions increased significantly with mean temperature (+4.4), minimum UTCI of the previous three days (+1.2) and current day hours of sunshine (+1), but decreased (−1.1) with more sunshine at a lag of two days prior to the current day. Maximum current day temperature increased ED admissions in both spring (+2.8) and fall (+1.2), while minimum temperature three days prior decreased ED admissions in those two seasons by −2.1 and −1.6, respectively. Apart from a small and marginally significant negative effect of three-day lagged minimum pressure in spring (−0.7), no other weather factor was chosen by the feature selection process for association to daily ED admissions. However, warning hours for long rainfall on the current day(−1.3) as well as three days prior (−0.7) reduced ED admissions in fall, and duration of wind gust warnings one day prior increased daily ED admissions by 1 visit.

3.2. Number of ED admissions by sex

Oktoberfest resulted in an average three-fold increase in ED admissions for males compared to females (+60 vs +18.3, respectively, Fig. 3). The influence of weekday on the number of male patients was limited to summer Sundays (−9.2) and fall Saturdays (+11.7), perhaps linked to Oktoberfest activities. For females, a weekday effect occurred only on Mondays during winter (+10.2) and summer (+6.4). The trend with year was similar for males and females in all seasons except for summer, where a positive effect was shown for males (+2.8) but not for females. In spring, summer and fall, the effect of holidays on ED admissions was slightly higher for males compared to females, but no influence on both was detected in winter.

Only a few weather conditions influenced the number of male patients delivered to the ED, with none in winter, and only duration of rain in fall. In summer, the number of male daily ED admissions increased with mean temperature (+2.85) and was slightly affected by duration of sunshine two days prior. Similarly, higher maximum temperatures in spring increased the number of male ED admissions (+1.3), as did hours of sunshine, while the three-day lagged temperature mean and maximum pressure had negative effects. More weather variables affected the number of female patients, and these covered all seasons. In summer, female ED admissions were associated with mean temperature (+2.0) and absolute humidity (+2.0), in spring with duration of strong storms (+1.7), maximum temperature and frost warning duration, in winter with two days lagged wind gust warnings, and in fall with minimum temperature. Fewer female patients were delivered to EDs with hail warning duration on the previous day (−3.1) in summer, with three-day lag of maximum precipitation intensity (−3.4) and three-day lag minimum temperature during winter, and with one-day lag maximum precipitation intensity (−1.2) and three-day lag minimum temperature and in fall.

The influence of pollutants on ED numbers of males was limited to PM_{10} in winter. In females, significant influences were detected for mean PM_{10} and maximum O_3 in spring, minimum O_3 in fall, and maximum PM_{10} and maximum NO in winter. However, the respective estimated influences were small.

3.3. Number of ED admissions by age

The number of ED admissions of older patients increased by 5–8 per year depending on the season, except for spring (+0.5) (Fig. 4). For adults such a trend was observed only in winter (+4.4), but not for children. The Oktoberfest had a large influence on the number of adult patients (+70.8), a small influence on older people (+6.4), and no influence on children (see also Figs. S1, S2). New Year's Day was associated with an enormous increase in the number of adult patients (+129.1), but had no effect on children and elderly people (see also Fig. S3). Other holidays similarly had no effect on the number of elderly patients, but were linked to fewer child patients in all seasons and fewer adult patients in all seasons except for fall. On Sundays in the ED, there were fewer elderly patients in summer and fall, fewer children patients in spring, summer and winter, and fewer adults in summer. There were

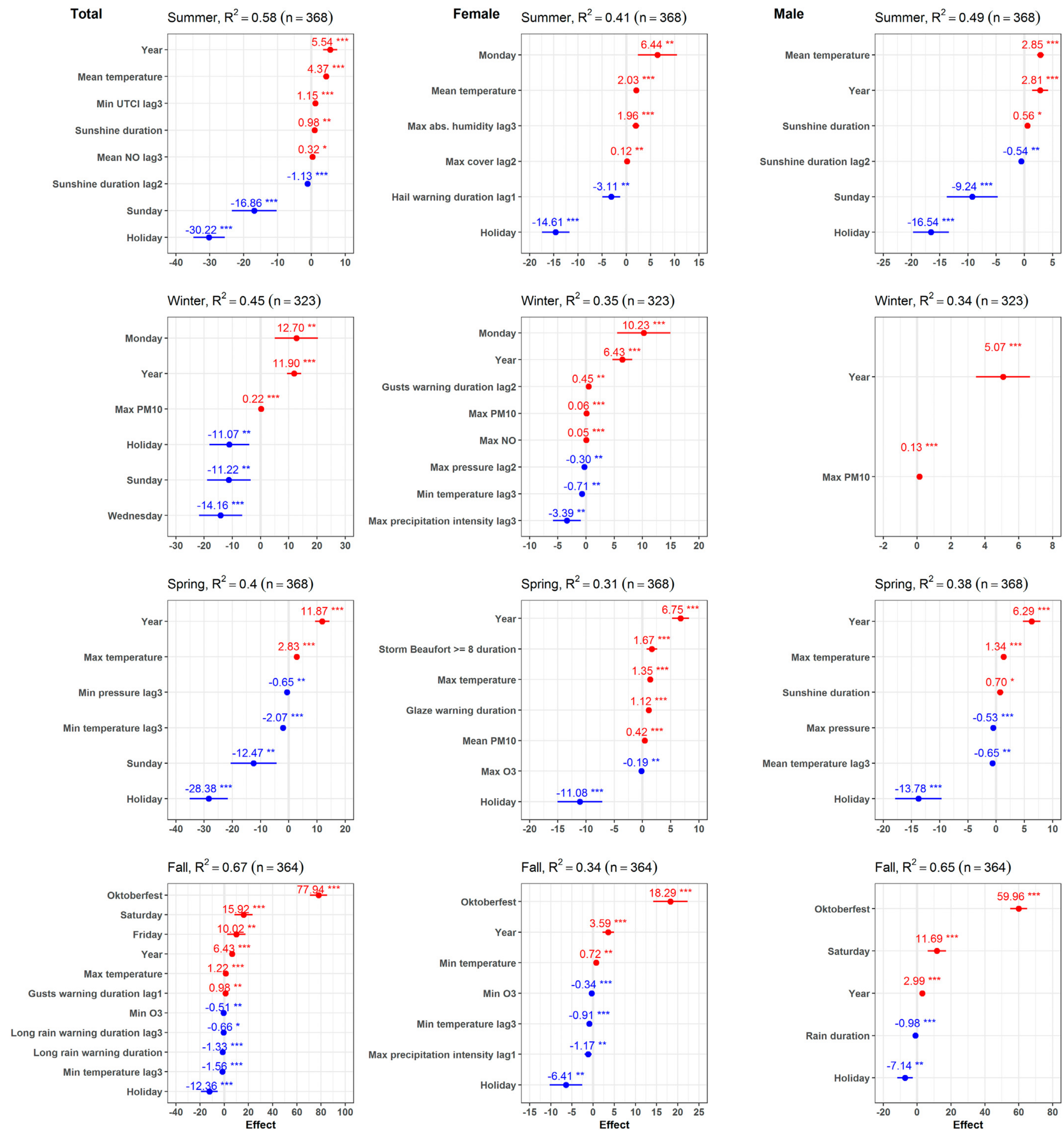

Fig. 3. Change in the number of daily ED admissions (Total, Female, and Male) associated with a unit increase in the respective factor in Munich (2014–2018) by season. Dots and bar lengths indicate estimates and confidence intervals. Star numbers indicate significance levels *: $P < .05$, **: $P < .01$, ***: $P < .001$. The associated R-squared value for each season is presented above the panel. For exact definitions of the predictor variables see Supplementary Table 3.

more adult patients only on Saturdays in fall and fewer patients on Fridays in summer.

The number of ED patients in fall decreased with one-day lag maximum precipitation, two-day lag cloud cover, and warnings of long rain for adult patients, two-day lag duration of long rain warnings for child patients, and three-day lag mean temperature for elderly people. Weather influence was not shown for adult and children ED numbers in winter. However, fewer elderly patients were delivered to EDs with higher three-day lag minimum temperature in winter.

For spring, only the current day maximum temperature had a positive influence on the number of adult (+1.3) and child patients (+0.3), whereas no climatic effect was observed for elderly in this season. During summer, the only weather factor that affected the number of elderly patients was hours of sunshine duration, with a marginal increase of one elderly ED delivery per 1 h increase in sunshine duration. For adults, current day temperature mean was the most influential factor (+3.0), followed by the three-day lag absolute humidity (1.6). For children, a positive effect of mean temperature (+1.1) and a negative

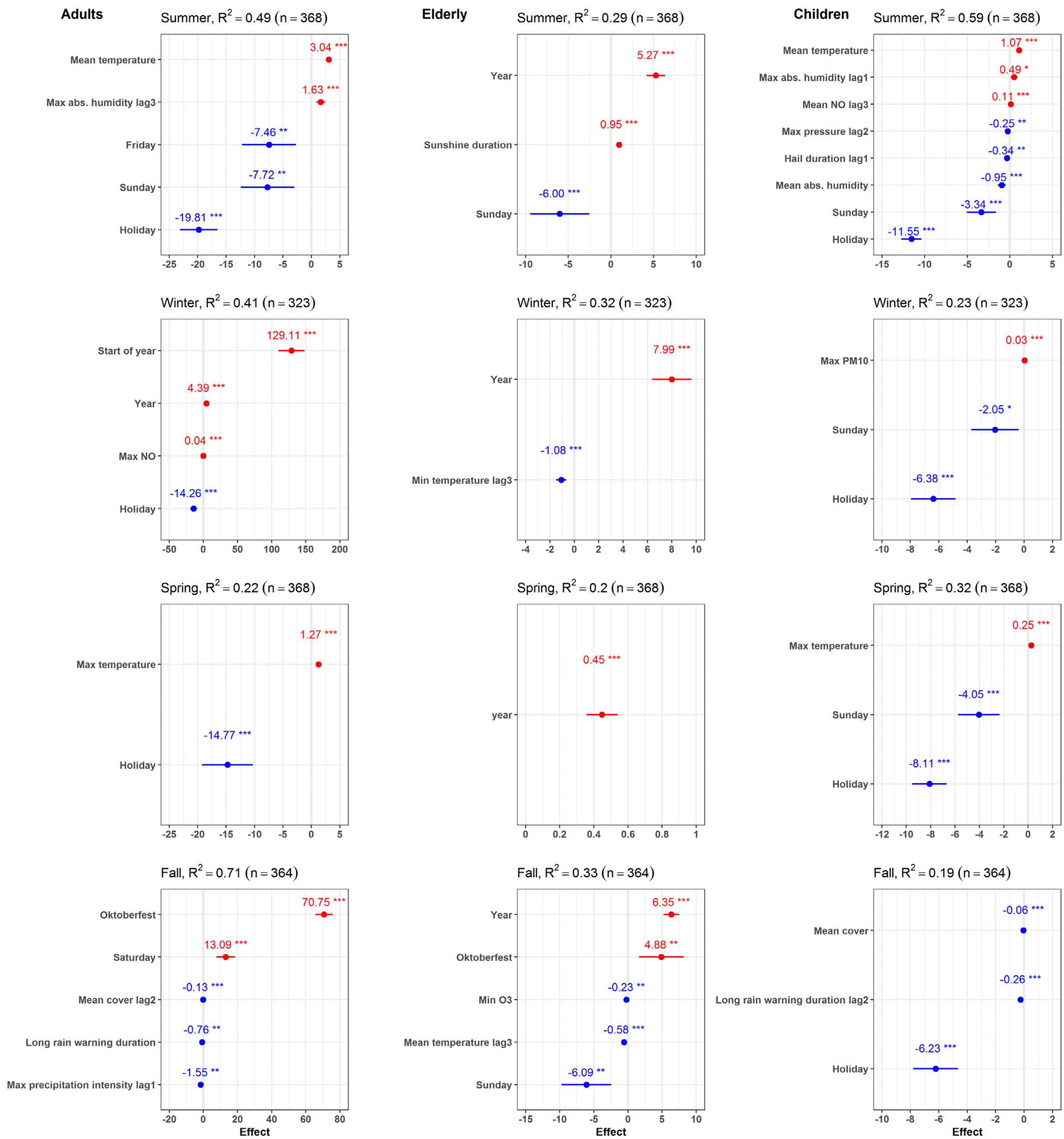

Fig. 4. Change in the number of daily ED admissions (Adults, Elderly, and Children) associated with a unit increase in the respective factor in Munich (2014–2018) by season. Dots and bar lengths indicate estimates and confidence intervals. Star numbers indicate significance levels *: $P < .05$, **: $P < .01$, ***: $P < .001$. The associated R-squared value for each season is presented above the panel. For exact definitions of the predictor variables see Supplementary Table 3.

effect of mean absolute humidity were detected (−1.0). To a lesser extent, summer ED admissions of children were affected by the lag values of maximum absolute humidity, maximum pressure, and duration of hailstorms.

The influence of pollutants on the number of patients was small when each age group was considered individually. Minimum O_3 concentrations had a negative effect on the elderly patients' numbers in fall, higher maximum NO concentrations in winter were linked to more adult patients. As for child patients, adult ED numbers increased with higher maximum concentrations of PM_{10} in winter, and with higher three-day lag mean NO concentrations in summer.

3.4. Number of ED admissions by department

Oktoberfest had a larger influence on ED admissions for surgical (+49.4) than internal cases (+30.5) (Fig. 5). Holidays presented fewer surgical cases in all seasons, but fewer internal cases only in spring and summer. Surgical case numbers were higher on Fridays

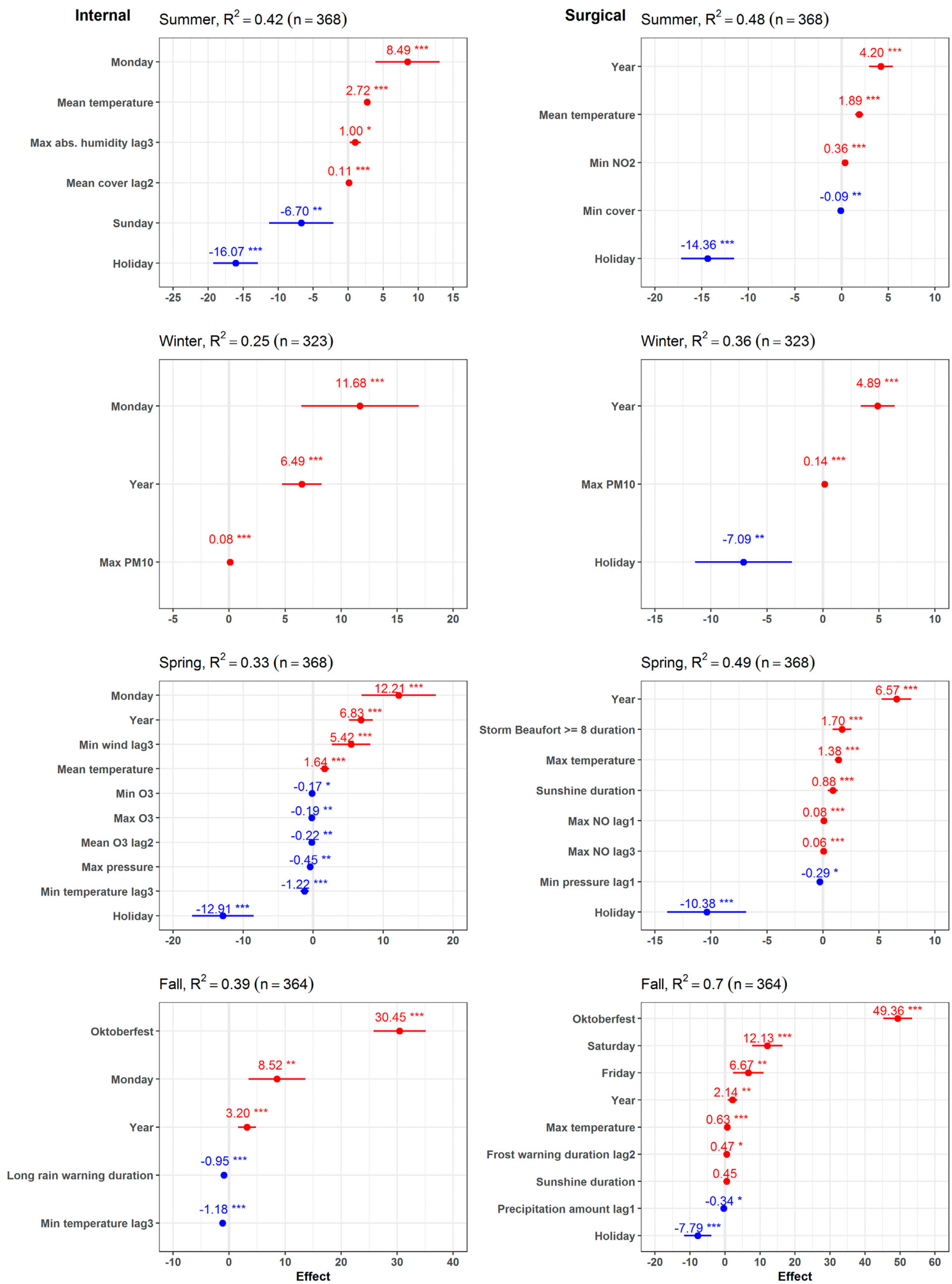

Fig. 5. Change in the number of daily ED admissions (Internal and Surgical) associated with a unit increase in the respective factor in Munich (2014–2018) by season. Dots and bar lengths indicate estimates and confidence intervals. Star numbers indicate significance levels *: $P < .05$, **: $P < .01$, ***: $P < .001$. The associated R-squared value for each season is presented above the panel. For exact definitions of the predictor variables see Supplementary Table 3.

and Saturdays, but only in the fall. Internal cases were higher on Mondays for all seasons, while lower on Sundays in summer.

No climatic effect on the number of surgical cases was recorded in winter. However, the number of surgical ED cases in summer increased with mean temperature. Duration of storms, maximum temperature and sunshine duration had a positive influence on the number of surgical cases during spring. In fall, more surgical ED admissions were associated with higher maximum temperatures, while precipitation amount on the previous day had a negative marginal effect.

Similarly, no influence of weather-related factors on internal cases in winter was found. More internal cases in summer were associated with higher mean temperature (+2.7), higher three-day lag maximum humidity (+1), and two-day lag mean cloud cover (+0.1). In spring, more internal cases were found with higher values of the three-day lag minimum wind speed (+5.4) and higher mean temperatures (+1.6), whereas less occurred with the three-day lag minimum temperature (−1.2) and maximum pressure. Internal cases decreased in fall with the three-day lag minimum temperature (−1.2) and duration of long rain warnings (−0.1).

The influence of air pollutants was minimal on both internal and surgical cases. The surgical cases increased with higher concentrations of NO_2 in summer, PM_{10} in winter, and lagged NO in spring. More internal cases were associated with lower O_3 concentrations in spring and higher PM_{10} concentrations in winter.

4. Discussion

Analyses of 5-year ED admissions for the greater Munich area supported the hypothesis that, in addition to calendar-related variables that had consistently strong effects, environmental factors also influenced daily ED numbers, although these effects varied with age, sex, and ED type. A considerable proportion of variance in ED numbers was explained by the analyses predictors (R^2 up to 0.71). One out of 32 subgroup models uniquely relied on calendar-related variables, but 6 additionally relied on air pollutants (mostly in winter), 15 on weather factors and 10 on both weather and pollutant factors.

4.1. The influence of calendar-related variables

Public holidays and school vacations consistently had a strong negative effect on ED numbers except among the elderly. Citizens over 70 years of age are generally retired in Germany, and their activities should therefore be independent of working days, unless they are involved through other working family members. However, the city of Munich relies heavily on public transportation, cycling and walking, with shops closed on Sundays, so the elderly are not immune to weather impacts on working days. Effects of holidays on ED numbers have been previously reported across various destinations across the globe with varying directions of impact. ED numbers were lower during holidays for low income populations in New York (Castner et al., 2016), and for Sao Paulo (Marcilio et al., 2013), but higher in Australia (McAllan et al., 2019). It proved to be more useful to model effects of specific holidays individually (Duwalage et al., 2020). In this study, fewer ED admissions were made on holidays (except New Year's Eve) in all seasons, but effect sizes were larger in spring and summer compared to fall and winter. This could be due to departure of families with children during the two-week spring and early summer school holidays, as well as the summer vacation, which typically witnesses a loss of 10% of German urban populations. Results here showed that in spring and summer, children had approximately 1/6 of the adult patient numbers, but nearly 1/2 of the adult ED holiday effect.

The Oktoberfest is an extraordinary event in the city of Munich and for its healthcare system. In 2019, the official Oktoberfest website estimated the total number of visitors within three weeks at 6.3 million, most of whom were men (Oktoberfest.de, 2020). 7.3 million l of beer were consumed in 2019. Data indicated an outstanding additional number of daily patients within this period (+78), especially among males (+60) and adults (+71). Similarly to the results found in this study, previous studies indicated that during the Oktoberfest, males in their twenties had the highest risk of landing in the ED (Binner et al., 2008). The Oktoberfest effect observed in this study was high for internal and disproportionately high for surgical cases. It was three times lower for females, much lower for the elderly, and nonexistent for children, an order most likely related to alcohol consumption habits. ED's throughout Bavaria prepare for the annual anticipated burden during the Oktoberfest.

On the day after New Year's Eve a high number of emergencies can be expected, particularly due to alcohol intoxication (Scholliers et al., 2019), injuries caused by fireworks (Serra López et al., 2020) and the deterioration of air quality after their use (Greven et al., 2019; Singh and Srivastava, 2020). In Munich, there was a strong effect on ED numbers only for the adult group (+129). However, additional patient numbers admitted on January 1st has been decreasing every year (see Fig. 1).

Year by year, ED admissions in Munich increased on average, especially in winter and spring. This effect was observed in all seasons in both the elderly as well as surgical cases, but in patients under 18 years of age, in none of the seasons. We assume that this is related to the low fertility rate in Germany, which has not exceeded a maximum of 1.6 in the last two decades (The World Bank Group, 2020), and the short span of five years of study.

Weekends had fewer ED visits compared to working days, as reported in the literature, especially for Monday (Calegari et al., 2016; Carvalho-Silva et al., 2018). In Australia, however, both Sundays and Mondays showed a 10% higher number of ED visits (Duwalage et al., 2020), which underlines the importance of addressing individual weekdays separately. Interestingly, there were more female and internal cases at Munich EDs on Mondays in summer and winter. On the other hand, there were fewer patients on Sundays, especially in summer and for internal cases.

Despite the reported increase in traffic accidents and suicide cases in Germany in the week after the daylight savings time change in spring (Lindenberger et al., 2019) and the increase in accidents due to insufficient sleep on the first Monday after the spring time change (Coren, 1996), such an effect was not observed on the number of ED admissions after adjusting for the meteorological and pollutant effects.

4.2. The influence of environmental variables

Temperature variability within each season is expected to influence morbidity and mortality rates under climate change scenarios, and this effect should already manifest in summer with higher mean temperatures (Malig et al., 2019; Klug et al., 2020). In this study of the greater Munich area, higher mean and maximum temperatures in spring and summer were associated with more ED admissions in almost all sex, age, and department subgroups. The effect size varied between ~1 to ~4 additional ED patients per °C, so that with more pronounced temperature anomalies in these seasons (e.g. +7 °C for the 2015 summer heatwave at the beginning of July) the effect could easily exceed +25. Various medical reasons are listed in the literature: Older people are admitted for diabetes and internal reasons, adults for fluid-electrolyte imbalances, and children for asthma and intestinal infections (Winquist et al., 2016). It is reported that the effect is higher in men than in females, and in rural than in urban areas (Lippmann et al., 2013). In the Netherlands, however, no such sex difference was found (van Loenhout et al., 2018). Most strikingly, no heat-related effect was shown for the elderly group in Munich. This could indicate appropriate heat warning systems in combination with a high standard of living. But in all other subgroups there was a strong effect of heat stress in spring and summer, which was mainly indicated by pure temperature variables rather than UTCI. For the city of Frankfurt (Germany), a high excess morbidity during the summer heat wave of 2015 was noted, leading to a ~200% increase in EMS operations due to heat-related disorders (Steul et al., 2019). If, as in our study a larger subgroup of internal cases is considered, this relative increase should be lower (~10%).

In addition to temperature, other weather variables that promote heat stress also had an effect on the number of ED visits in spring, summer and fall. Longer periods of sunshine and less cloud cover increased the total number of ED visits predominantly in summer. Sunshine duration may cause cardiac arrest, especially in early summer (Onozuka and Hagihara, 2017). Humidity is an important factor for the apparent temperature (Min et al., 2019), which reflects human discomfort on hot and humid days. The main source of body cooling on warm days is the evaporation of sweat, which is hindered when the air is almost saturated. The current study identified this effect of humidity in summer to increase ED numbers in females, children, adults and internal cases with effect sizes between 1 and 2 per g m^{-3} water vapor.

On the other hand, higher morbidity in winter is associated with lower minimum temperatures (Klug et al., 2020). In Munich, lower lagged minimum temperatures were associated with more ED visits by elderly and females in winter and more internal and total visits in the transitional seasons (effect sizes of −1 to −2 per °C). This lagged effect could be explained by colds and influenza, where at-risk patients were admitted to ED only a few days after recording cold minimum temperatures. It is known that women (Zhou et al., 2014) and older people (Baumgartner et al., 2008; Chen et al., 2019) are more susceptible to cold weather. In fall, a combined effect was observed here, as both lagged minimum and maximum temperature influenced ED visits. Higher lagged minimum temperatures decreased the number of ED visits in elderly people, females and internal cases, and in contrast higher maximum temperatures increased the total number of ED visits.

The other weather variables were less frequently included in the models, but still showed a consistent pattern, e.g. to what is perceived as "bad" rainy weather. Warnings against long rains as well as long rain duration (also on preceding days) in fall were associated with lower ED numbers in total cases and all subgroups expect the elderly. In Ohio, USA, ED visits decreased with precipitation (Faryar, 2013). In South Korea, ED visits decreased on the same day of rainfall and increased on the following days (Lee et al., 2016). The positive lagged effect was also reported in Wisconsin (Drayna et al., 2010). This discrepancy could be caused by the different geographical location, as the seasons were treated separately and precipitation was not limited to rain. Daily sum of rain was not chosen in the feature selection process, most likely because it is highly variable in time and space. Rain or the threat to rain over a long period of time would result in the tendency to stay at home. A similar explanation might be assumed for the observation that hail warnings in summer were associated with decreased ED numbers in females and children.

The second minor, but consistent pattern is related to storm and other hazards indicated by e.g. storm duration and warning, warning against gusts, minimum wind speed, low pressure systems as well as warnings against hail and slipperiness. Several cases in spring, as well as in other seasons, witnessed increasing numbers of ED visits in total cases, males and females, as well as internal and surgical cases, under these circumstances. In the literature, only dust storm events with extremely high levels of particulate matter were reported to be associated with large increases in ED visits (Merrifield et al., 2013), and no effect of strong winds, thunderstorm or tornadoes was reported for a county in Ohio, US (Faryar, 2013).

Concerning air quality, ambient pollutants consistently posed a significant effect on the number of ED visits. The effects sizes as reported in Figs. 3 to 5 appear small at first glance, but must be related to the regularly observed fluctuations, as indicated by their SD in Table 2. Coarse particulate matter (PM_{10}) in winter was associated with increased ED visits in most subgroups with effect sizes up to 0.22 per μg m^{-3} (total cases, see Fig. 3). Assuming twice the PM_{10} SD in winter, this would translate into ~12 additional daily cases. Additionally, emergency cases in some subgroups were positively associated with NO concentrations in winter and (with a lagged effect) in summer. Again, based on SD and effect size, this could result in up to ~6 additional ED cases. The World Health Organization et al. (2003) concluded that cardiovascular deaths and morbidity indicators are related to ambient PM. High concentrations of fine particles are known to increase ED visits due to hypertension (Szyszkowicz et al., 2012) and cardiopulmonary diseases (Feng et al., 2019). Winter inversions also increase the rates of ED visits due to asthma (Beard et al., 2012), which could be linked to the trapping of pollutants in the cold layer near the surface intensifying their concentrations.

It is worth noting that higher O_3 concentrations, potentially indicating photochemical smog episodes, were associated with fewer ED visits in the transitional seasons, especially in total cases, females, elderly and internal cases. Surface ozone is harmful to human health (Krzyzanowski and Cohen, 2008), and high O_3 concentration is expected to increase the number of ED visits due to asthma (Stieb et al., 1996). However, a negative association between O_3 and cardiac admissions was found in London, but positive in Hong Kong (Wong et al., 2002). Under the assumption that O_3 levels currently observed in the transitional seasons are below critical thresholds for short-term exposure, the detected O_3 effect may be a proxy for other ones, e.g. less NO_x usually scavenging O_3. Independent (per se) O_3 effects have been mostly found in summer (World Health Organization et al., 2003).

4.3. Limitations

ED admissions in this research are based solely on cases transported via the EMS ambulance system in Munich, and does not include cases which are transported by other means.

Reported statistical associations do not imply causality. For example, Mondays are linked to higher activities on the roads, thereby increasing the concentration of pollutants. So the observed association between pollutants and ED admissions could be due to the unmeasured confounder of increased traffic, which increases both pollutants and ED admissions. Despite the high number of variables tested and included, there still might be suitable predictors which were not included, such as atmospheric concentrations of allergenic pollen or other events bringing more visitors to Munich, including festivals and job fairs.

Specific variables could have been omitted by the automatic model selection due to high correlation with other variables as the model selection process is not able to unravel multi-collinear effects. Additionally, the span of five years may be insufficient to capture year-to-year variability of weather factors, especially heatwaves (Schär et al., 2004), which advocates continual ED visit and rescue service monitoring in tandem with associated weather variables.

5. Conclusions

Although the complex and combined effects of pollutants and weather on ED admissions vary by season, sex, age, and department, the overall pattern suggests that with ongoing climate change, characterized by more hot days and increased variability of rainfall as well as drought periods (Seneviratne et al., 2012), numbers of daily ED admissions could continue to increase, warranting more resource planning. Special attention should be paid to NO and PM_{10} concentrations in winter in order to prevent higher morbidity, potentially requiring emergency rescue operations. Realistic prediction of rescue service operations considering in addition to calendar-related factors, weather and air pollutants in winter will improve the healthcare system and guide the daily allocation of resources and staff at the hospital and city level.

CRediT authorship contribution statement

Wael Ghada: Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Nicole Estrella:** Writing - review & editing. **Dominik Pfoerringer:** Writing - review & editing. **Karl-Georg Kanz:**

Writing - review & editing. **Viktoria Bogner-Flatz:** Writing - review & editing. **Donna P. Ankerst:** Methodology, Writing - review & editing, Supervision. **Annette Menzel:** Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.143772.

References

Bavarian State Office for environment. 2020. Mesurement archive of air pollutants. https://www.lfu.bayern.de/luft/immissionsmessungen/messwertarchiv/index.htm. Accessed 2020 Jun 4.

Oktoberfest.de. 2020. The official Oktoberfest review 2019: The Official Website for the Oktoberfest in Munich. https://www.oktoberfest.de/en/magazine/oktoberfest-news/2019/the-official-oktoberfest-review-2019. Accessed 2020 Jun 11.

Achakulwisut, P., Brauer, M., Hystad, P., Anenberg, S.C., 2019. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. The Lancet Planetary Health 3 (4), e166–e178. https://doi.org/10.1016/S2542-5196(19)30046-4.

Anenberg, S.C., Henze, D.K., Tinney, V., Kinney, P.L., Raich, W., Fann, N., et al., 2018. Estimates of the global burden of ambient formula: see text, ozone, and formula: see text on asthma incidence and emergency room visits. Environ. Health Perspect. 126 (10), 107004. https://doi.org/10.1289/EHP3766.

Baumgartner, E.A., Belson, M., Rubin, C., Patel, M., 2008. Hypothermia and other cold-related morbidity emergency department visits: United States, 1995–2004. Wilderness Environ Med 19 (4), 233–237. https://doi.org/10.1580/07-WEME-OR-104.1.

Bavarian Ministry of education. 2020. Historical official holidays for Bavaria,Germany. https://www.km.bayern.de/schueler/schule-und-mehr/termine/ferientermine.html. Accessed 2020 Jun 4.

Beard, J.D., Beck, C., Graham, R., Packham, S.C., Traphagan, M., Giles, R.T., et al., 2012. Winter temperature inversions and emergency department visits for asthma in Salt Lake County, Utah, 2003–2008. Environ. Health Perspect. 120 (10), 1385–1390. https://doi.org/10.1289/ehp.1104349.

Bhaskaran, K., Gasparrini, A., Hajat, S., Smeeth, L., Armstrong, B., 2013. Time series regression studies in environmental epidemiology. Int. J. Epidemiol. 42 (4), 1187–1195. https://doi.org/10.1093/ije/dyt092.

Binner, C., Selinski, S., Barysch, M.J., Pölcher, C., Schormann, W., Hermes, M., et al., 2008. Munich Oktoberfest experience: remarkable impact of sex and age in ethanol intoxication. Arch. Toxicol. 82 (12), 933–939. https://doi.org/10.1007/s00204-008-0373-z.

Bolt, S., Sparks, R., 2013. Detecting and diagnosing hotspots for the enhanced management of hospital Emergency Departments in Queensland, Australia. BMC Med Inform Decis Mak 13, 132. https://doi.org/10.1186/1472-6947-13-132.

Boyle, J., Jessup, M., Crilly, J., Green, D., Lind, J., Wallis, M., et al., 2012. Predicting emergency department admissions. Emerg. Med. J. 29 (5), 358–365. https://doi.org/10.1136/emj.2010.103531.

Breitner, S., Wolf, K., Devlin, R.B., Diaz-Sanchez, D., Peters, A., Schneider, A., 2014. Short-term effects of air temperature on mortality and effect modification by air pollution in three cities of Bavaria, Germany: a time-series analysis. Sci. Total Environ. 485-486, 49–61. https://doi.org/10.1016/j.scitotenv.2014.03.048.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., et al., 2012. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). Int. J. Biometeorol. 56 (3), 481–494. https://doi.org/10.1007/s00484-011-0454-1.

Calegari, R., Fogliatto, F.S., Lucini, F.R., Neyeloff, J., Kuchenbecker, R.S., Schaan, B.D., 2016. Forecasting daily volume and acuity of patients in the emergency department. Comput Math Methods Med 2016, 3863268. https://doi.org/10.1155/2016/3863268.

Carvalho-Silva, M., Monteiro, M.T.T., de Sá-Soares, F., Dória-Nóbrega, S., 2018. Assessment of forecasting models for patients arrival at Emergency Department. Operations Research for Health Care 18, 112–118. https://doi.org/10.1016/j.orhc.2017.05.001.

Castner, J., Yin, Y., Loomis, D., Hewner, S., 2016. Medical mondays: ED utilization for medicaid recipients depends on the day of the week, season, and holidays. J. Emerg. Nurs. 42 (4), 317–324. https://doi.org/10.1016/j.jen.2015.12.010.

Chen, T.-H., Du, X.L., Chan, W., Zhang, K., 2019. Impacts of cold weather on emergency hospital admission in Texas, 2004–2013. Environ. Res. 169, 139–146. https://doi.org/10.1016/j.envres.2018.10.031.

Coren, S., 1996. Daylight savings time and traffic accidents. N. Engl. J. Med. 334 (14), 924. https://doi.org/10.1056/NEJM199604043341416.

Drayna, P., McLellan, S.L., Simpson, P., Li, S.-H., Gorelick, M.H., 2010. Association between rainfall and pediatric emergency department visits for acute gastrointestinal illness. Environ. Health Perspect. 118 (10), 1439–1443. https://doi.org/10.1289/ehp.0901671.

Duwalage, K.I., Burkett, E., White, G., Wong, A., Thompson, M.H., 2020. Forecasting daily counts of patient presentations in Australian emergency departments using statistical models with time-varying predictors. Emerg Med Australas. https://doi.org/10.1111/1742-6723.13481.

Erbas, B., Akram, M., Dharmage, S.C., Tham, R., Dennekamp, M., Newbigin, E., et al., 2012. The role of seasonal grass pollen on childhood asthma emergency department presentations. Clin. Exp. Allergy 42 (5), 799–805. https://doi.org/10.1111/j.1365-2222.2012.03995.x.

Faryar, K.A., 2013. The Effects of Weekday, Season, Federal Holidays, and Severe Weather Conditions on Emergency Department Volume in Montgomery County, Ohio.

Feng, W., Li, H., Wang, S., van Halm-Lutterodt, N., An, J., Liu, Y., et al., 2019. Short-term PM10 and emergency department admissions for selective cardiovascular and respiratory diseases in Beijing, China. Sci. Total Environ. 657, 213–221. https://doi.org/10.1016/j.scitotenv.2018.12.066.

Ferrari, U., Exner, T., Wanka, E.R., Bergemann, C., Meyer-Arnek, J., Hildenbrand, B., et al., 2012. Influence of air pressure, humidity, solar radiation, temperature, and wind speed on ambulatory visits due to chronic obstructive pulmonary disease in Bavaria, Germany. Int. J. Biometeorol. 56 (1), 137–143. https://doi.org/10.1007/s00484-011-0405-x.

Gabriel, K.M.A., Endlicher, W.R., 2011. Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. Environ. Pollut. 159 (8–9), 2044–2050. https://doi.org/10.1016/j.envpol.2011.01.016.

Greven, F.E., Vonk, J.M., Fischer, P., Duijm, F., Vink, N.M., Brunekreef, B., 2019. Air pollution during new year's fireworks and daily mortality in the Netherlands. Sci. Rep. 9 (1), 5735. https://doi.org/10.1038/s41598-019-42080-6.

Hertel, S., Le Tertre, A., Jöckel, K.-H., Hoffmann, B., 2009. Quantification of the heat wave effect on cause-specific mortality in Essen, Germany. Eur. J. Epidemiol. 24 (8), 407–414. https://doi.org/10.1007/s10654-009-9359-2.

Hondula, D.M., Barnett, A.G., 2014. Heat-related morbidity in Brisbane, Australia: spatial variation and area-level predictors. Environ. Health Perspect. 122 (8), 831–836. https://doi.org/10.1289/ehp.1307496.

Jilani, T., Housley, G., Figueredo, G., Tang, P.-S., Hatton, J., Shaw, D., 2019. Short and long term predictions of hospital emergency department attendances. Int. J. Med. Inform. 129, 167–174. https://doi.org/10.1016/j.ijmedinf.2019.05.011.

Kim, S.-Y., Peel, J.L., Hannigan, M.P., Dutton, S.J., Sheppard, L., Clark, M.L., et al., 2012. The temporal lag structure of short-term associations of fine particulate matter chemical constituents and cardiovascular and respiratory hospitalizations. Environ. Health Perspect. 120 (8), 1094–1099. https://doi.org/10.1289/ehp.1104721.

Kingsley, S.L., Eliot, M.N., Gold, J., Vanderslice, R.R., Wellenius, G.A., 2016. Current and projected heat-related morbidity and mortality in Rhode Island. Environ. Health Perspect. 124 (4), 460–467. https://doi.org/10.1289/ehp.1408826.

Klug, M., Barash, Y., Bechler, S., Resheff, Y.S., Tron, T., Ironi, A., et al., 2020. A gradient boosting machine learning model for predicting early mortality in the emergency department triage: devising a nine-point triage score. J. Gen. Intern. Med. 35 (1), 220–227. https://doi.org/10.1007/s11606-019-05512-7.

Krzyzanowski, M., Cohen, A., 2008. Update of WHO air quality guidelines. Air Qual. Atmos. Health 1 (1), 7–13. https://doi.org/10.1007/s11869-008-0008-9.

Lee, H.J., Jin, M.H., Lee, J.H., 2016. The association of weather on pediatric emergency department visits in Changwon, Korea (2005–2014). Sci. Total Environ. 551-552, 699–705. https://doi.org/10.1016/j.scitotenv.2016.02.015.

Lindauer, M., Schmid, H.P., Grote, R., Steinbrecher, R., Mauder, M., Wolpert, B., 2017. A simple new model for incoming solar radiation dependent only on screen-level relative humidity. J. Appl. Meteor. Climatol. 56 (7), 1817–1825. https://doi.org/10.1175/JAMC-D-16-0085.1.

Lindenberger, L.M., Ackermann, H., Parzeller, M., 2019. The controversial debate about daylight saving time (DST)-results of a retrospective forensic autopsy study in Frankfurt/Main (Germany) over 10 years (2006–2015). Int. J. Legal Med. 133 (4), 1259–1265. https://doi.org/10.1007/s00414-018-1960-z.

Lippmann, S.J., Fuhrmann, C.M., Waller, A.E., Richardson, D.B., 2013. Ambient temperature and emergency department visits for heat-related illness in North Carolina, 2007-2008. Environ. Res. 124, 35–42. https://doi.org/10.1016/j.envres.2013.03.009.

van Loenhout, J.A.F., Delbiso, T.D., Kiriliouk, A., Rodriguez-Llanes, J.M., Segers, J., Guha-Sapir, D., 2018. Heat and emergency room admissions in the Netherlands. BMC Public Health 18 (1), 108. https://doi.org/10.1186/s12889-017-5021-1.

Lowe, R., Ballester, J., Creswick, J., Robine, J.-M., Herrmann, F.R., Rodó, X., 2015. Evaluating the performance of a climate-driven mortality model during heat waves and cold spells in Europe. Int. J. Environ. Res. Public Health 12 (2), 1279–1294. https://doi.org/10.3390/ijerph120201279.

Luginaah, I.N., Fung, K.Y., Gorey, K.M., Webster, G., Wills, C., 2005. Association of ambient air pollution with respiratory hospitalization in a government-designated "area of

concern": the case of Windsor, Ontario. Environ. Health Perspect. 113 (3), 290–296. https://doi.org/10.1289/ehp.7300.
Malig, B.J., Wu, X.M., Guirguis, K., Gershunov, A., Basu, R., 2019. Associations between ambient temperature and hepatobiliary and renal hospitalizations in California, 1999 to 2009. Environ. Res. 177, 108566. https://doi.org/10.1016/j.envres.2019.108566.
Marcilio, I., Hajat, S., Gouveia, N., 2013. Forecasting daily emergency department visits using calendar variables and ambient temperature readings. Acad. Emerg. Med. 20 (8), 769–777. https://doi.org/10.1111/acem.12182.
Matzarakis, A., Rutz, F., Mayer, H., 2007. Modelling radiation fluxes in simple and complex environments–application of the RayMan model. Int. J. Biometeorol. 51 (4), 323–334. https://doi.org/10.1007/s00484-006-0061-8.
McAllan, F.J., Egerton-Warburton, D., O'Reilly, G., Weiland, T.J., Jelinek, G.A., 2019. Planning for the future: Modelling daily emergency department presentations in an Australian capital city. Emerg Med Australas 31 (5), 750–755. https://doi.org/10.1111/1742-6723.13245.
Merrifield, A., Schindeler, S., Jalaludin, B., Smith, W., 2013. Health effects of the September 2009 dust storm in Sydney, Australia: did emergency department visits and hospital admissions increase? Environ. Health 12, 32. https://doi.org/10.1186/1476-069X-12-32.
Min, M., Shi, T., Ye, P., Wang, Y., Yao, Z., Tian, S., et al., 2019. Effect of apparent temperature on daily emergency admissions for mental and behavioral disorders in Yancheng, China: a time-series study. Environ. Health 18 (1), 98. https://doi.org/10.1186/s12940-019-0543-x.
Onozuka, D., Hagihara, A., 2017. Within-summer variation in out-of-hospital cardiac arrest due to extremely long sunshine duration. Int. J. Cardiol. 231, 120–124. https://doi.org/10.1016/j.ijcard.2016.12.179.
Ostro, B., Roth, L., Malig, B., Marty, M., 2009. The effects of fine particle components on respiratory hospital admissions in children. Environ. Health Perspect. 117 (3), 475–480. https://doi.org/10.1289/ehp.11848.
Pförringer, D., Breu, M., Crönlein, M., Kolisch, R., Kanz, K.-G., 2018. Closure simulation for reduction of emergency patient diversion: a discrete agent-based simulation approach to minimizing ambulance diversion. Eur. J. Med. Res. 23 (1), 32. https://doi.org/10.1186/s40001-018-0330-0.
Salway, R.J., Valenzuela, R., Shoenberger, J.M., Mallon, W.K., Viccellio, A., 2017. Emergency department (ED) overcrowding: evidence-based answers to frequently asked questions. Revista Médica Clínica Las Condes 28 (2), 213–219. https://doi.org/10.1016/j.rmclc.2017.04.008.
Schaffer, A., Muscatello, D., Broome, R., Corbett, S., Smith, W., 2012. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. Environ. Health 11 (1), 3. https://doi.org/10.1186/1476-069X-11-3.
Schär, C., Vidale, P.L., Lüthi, D., Frei, C., Häberli, C., Liniger, M.A., et al., 2004. The role of increasing temperature variability in European summer heatwaves. Nature 427 (6972), 332–336. https://doi.org/10.1038/nature02300.
Scholliers, A., Gogaert, S., de Fré, D., D'haese, I., Vandycke, C., 2019. Happy new year! Do new year's eve festivities influence the workload of the Emergency Department of an urban hospital? Prehosp. Disaster med. 34 (s1), s133–s134. https://doi.org/10.1017/S1049023X19002929.
Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., et al., 2012. Changes in Climate Extremes and their Impacts on the Natural Physical Environment.
Serra López, V.M., Cheema, A.N., Gray, B.L., Pirruccio, K., Kazmers, N.H., 2020. Epidemiology of fireworks-related injuries to the upper extremity in the United States from 2011 to 2017. Journal of Hand Surgery Global Online 2 (3), 117–120. https://doi.org/10.1016/j.jhsg.2020.03.003.
Shiue, I., Perkins, D.R., Bearman, N., 2016. Hospital admissions of hypertension, angina, myocardial infarction and ischemic heart disease peaked at physiologically equivalent temperature 0 °C in Germany in 2009–2011. Environ. Sci. Pollut. Res. Int. 23 (1), 298–306. https://doi.org/10.1007/s11356-015-5224-x.
Singh, A.K., Srivastava, A., 2020. The impact of fireworks emissions on air quality in Delhi. India. Environmental Claims Journal, 1–21 https://doi.org/10.1080/10406026.2020.1756078.
Smith K, Woodward A, Campbell-Lendrum D, Chadee D, Honda Y, Liu Q, et al. 2014. Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [place unknown]: Cambridge University Press, 709–754.
Steul, K., Jung, H.-G., Heudorf, U., 2019. Hitzeassoziierte Morbidität: surveillance in Echtzeit mittels rettungsdienstlicher Daten aus dem Interdisziplinären Versorgungsnachweis (IVENA) [heat-related morbidity: real-time surveillance via rescue service operations data from the interdisciplinary care capacity proof system (IVENA)]. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 62 (5), 589–598. https://doi.org/10.1007/s00103-019-02938-6.
Stieb, D.M., Burnett, R.T., Beveridge, R.C., Brook, J.R., 1996. Association between ozone and asthma emergency department visits in Saint John, New Brunswick, Canada. Environ. Health Perspect. 104 (12), 1354–1360. https://doi.org/10.1289/ehp.961041354.
Szyszkowicz, M., Rowe, B.H., Brook, R.D., 2012. Even low levels of ambient air pollutants are associated with increased emergency department visits for hypertension. Can J Cardiol 28 (3), 360–366. https://doi.org/10.1016/j.cjca.2011.06.011.
The World Bank Group. 2020. Fertility rate, total (births per woman) - Germany | Data. https://data.worldbank.org/indicator/SP.DYN.TFRT.IN?end=2018&locations=DE&start=1970&view=chart. Accessed 2020 Jun 11.
Vaneckova, P., Bambrick, H., 2013. Cause-specific hospital admissions on hot days in Sydney, Australia. PLoS One 8 (2), e55459. https://doi.org/10.1371/journal.pone.0055459.
Wang, Y.-C., Lin, Y.-K., 2014. Association between temperature and emergency room visits for cardiorespiratory diseases, metabolic syndrome-related diseases, and accidents in metropolitan Taipei. PLoS One 9 (6), e99599. https://doi.org/10.1371/journal.pone.0099599.
Wargon, M., Guidet, B., Hoang, T.D., Hejblum, G., 2009. A systematic review of models for forecasting the number of emergency department visits. Emerg. Med. J. 26 (6), 395–399. https://doi.org/10.1136/emj.2008.062380.
Wargon, M., Casalino, E., Guidet, B., 2010. From model to forecasting: a multicenter study in emergency departments. Acad. Emerg. Med. 17 (9), 970–978. https://doi.org/10.1111/j.1553-2712.2010.00847.x.
Wargon, M., Brun-Ney, D., Beaujouan, L., Casalino, E., 2018. No more winter crisis? Forecasting daily bed requirements for emergency department admissions to hospital. Eur J Emerg Med 25 (4), 250–256. https://doi.org/10.1097/MEJ.0000000000000451.
Deutscher Wetterdienst. 2020. Climate Data Center. ftp://opendata.dwd.de/climate_environment/CDC/. Accessed 2020 Jun 4.
Winquist, A., Grundstein, A., Chang, H.H., Hess, J., Sarnat, S.E., 2016. Warm season temperatures and emergency department visits in Atlanta, Georgia. Environ. Res. 147, 314–323. https://doi.org/10.1016/j.envres.2016.02.022.
Wong, C.-M., Atkinson, R.W., Anderson, H.R., Hedley, A.J., Ma, S., Chau, P.Y.-K., et al., 2002. A tale of two cities: effects of air pollution on hospital admissions in Hong Kong and London compared. Environ. Health Perspect. 110 (1), 67–77. https://doi.org/10.1289/ehp.0211067.
World Health Organization, et al. 2003. Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide: report on a WHO working group, Bonn, Germany 13-15 January 2003. [place unknown]: Copenhagen: WHO Regional Office for Europe. Accessed.
Zhou, M.G., Wang, L.J., Liu, T., Zhang, Y.H., Lin, H.L., Luo, Y., et al., 2014. Health impact of the 2008 cold spell on mortality in subtropical China: the climate and health impact national assessment study (CHINAs). Environ. Health 13, 60. https://doi.org/10.1186/1476-069X-13-60.