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Effects of extreme temperatures, fine particles and ozone on hourly ambulance dispatches

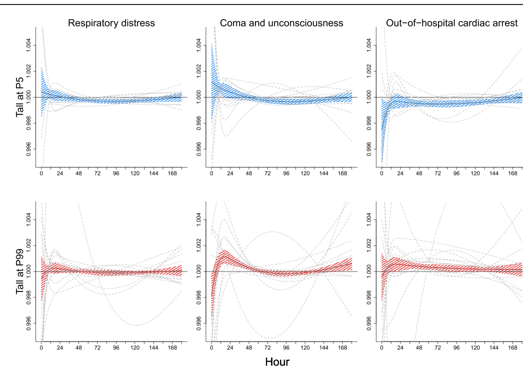
Yu-Chun Wang [a], Fung-Chang Sung [b,c,d], Yi-Jhih Chen [a], Chia-Pei Cheng [a], Yu-Kai Lin [e,*]

[a] *Department of Environmental Engineering, College of Engineering, Chung Yuan Christian University, 200 Chung-Pei Road, Zhongli 320, Taiwan*
[b] *Department of Health Services Administration, China Medical University, 91 Hsueh-Shih Road, Taichung 404, Taiwan*
[c] *Management Office for Health Data, China Medical University Hospital, Taichung 404, Taiwan*
[d] *Department of Food Nutrition and Health Biotechnology, Asia University, Taichung 413, Taiwan*
[e] *Department of Health and Welfare, University of Taipei, 101 Zhongcheng Road Sec. 2, Taipei 111, Taiwan*

HIGHLIGHTS

- Hourly 10-year data on ambulance dispatches and on ambient environment are available simultaneously for subtropical island.
- The ambulance call risk associated with pollutants could be indirect associations with the temperature.
- The daily and hourly acute health responses to ambient environment changes should be compared.
- Findings provide public health sectors to consider more actions to response to extreme environmental conditions.

GRAPHICAL ABSTRACT



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ABSTRACT

There is a dearth of research on the hourly risk of ambulance dispatches with respect to ambient conditions. We evaluated hourly relative risks (RR) and 95% confidence interval (CI) of ambulance dispatches in Taiwan to treat respiratory distress, coma and unconsciousness, and out-of-hospital cardiac arrest (OHCA), from 2006 to 2015. We considered island-wide ambient temperatures, fine particulate matter ($PM_{2.5}$), and ozone (O_3) at lag 0–180 h while using a distributed lag nonlinear model and meta-analysis.

Results showed the pooled risks peaked at lag 16–18 h for all ambulance dispatches at 99th percentile of hourly temperature (32 °C, versus reference temperature of 25 °C), with significant excess risk of 0.11% (95% CI; 0.06, 0.17) for coma and unconsciousness, and 0.06% (95% CI; 0.01, 0.11) for OHCA. The risks of exposure to 90th percentile of hourly O_3 of 52.3 ppb relative to the Q1 level of 17.3 ppb peaked at lag 14 h, with excess risk of 0.17% (95% CI; 0.11, 0.23) for respiratory distress, 0.11% (95% CI; 0.06, 0.16) for coma and unconsciousness, and 0.07% (95% CI; 0.01, 0.14) for OHCA. The population exposed to reference temperatures of 28 °C, 20 °C, and 26 °C were exposed to the lowest levels of ambulance dispatches risk for respiratory distress, coma and unconsciousness, and OHCA, respectively; the highest cumulative 0–96 h RRs of ambulance dispatches were 1.27 (95% CI; 1.19, 1.35) for OHCA at 5th percentile temperatures and 1.25 (95% CI; 1.11, 1.41) for OHCA at 99th percentile temperatures. Following an accumulating lag of 0–96 h, no significant risk was identified for hourly levels of $PM_{2.5}$ and O_3.
In conclusion, the analytical results of hourly data speak to immediate and real-time responses to environmental changes, rather than to short-term relationships. In our analyses, we emphasized health events in extreme heat; thus, we recommend a comparative study of daily versus hourly associations.

* Corresponding author at: Department of Health and Welfare, University of Taipei, 101 Zhongcheng Road Sec. 2, Taipei 111, Taiwan.
E-mail address: yklin@utaipei.edu.tw (Y.-K. Lin).

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1. Introduction

Many studies link ambient environmental conditions to various morbidities and mortalities (Achilleos et al., 2017; Atkinson et al., 2016; Guo et al., 2014; Lin et al., 2019; Song et al., 2017). However, knowledge of the link to the risk of ambulance dispatch is limited, given the lack of sufficient records. Ambulance services are emergency services that provide prehospital urgent care for severe conditions or injuries (Meghoo et al., 2019). Ambulance call-out data containing meaningful real-time information can be linked to temporal environmental conditions to assess the impact of temperature and air pollution on human health (Mahmood et al., 2017).

Studies from Italy, China, Japan, and Taiwan report that ambulance dispatches for out-of-hospital cardiac arrest (OHCA), respiratory disorders, and chest pain increase during times of extreme temperature (Alessandrini et al., 2011; Niu et al., 2016; Onozuka and Hagihara, 2016; Wang et al., 2020). Researchers usually accumulate the lag effects of ambient temperature on morbidity from lag 0 to lag 3 days (Phung et al., 2016); only a limited number of studies assess the temperature–health lag response on an hourly scale (Cui et al., 2020; Guo, 2017; Xu et al., 2019). Information regarding exposure–lag response between ambulance dispatches and the ambient environment critically informs authorities' planning vis-à-vis emergency medical services and resource reallocation.

Events required ambulance dispatches may relate not only to ambient temperatures but also to other environmental conditions and population characteristics. Cui et al. (2020) found that an hourly heat wave in excess of 32.1 °C leads to a greater number of ambulance calls within a few hours than that seen with cold spells below −2.5 °C. These researchers, however, did not consider the impact of air pollution; indeed, researchers should assess ambulance dispatches use while considering factors additional to ambient temperature. The current study fills this research gap within the study context of Taiwan.

Taiwan has a hot and humid subtropical climate, given its location in Southeast Asia, near to the Pacific Ocean. Taiwan's annual average temperature is 24 °C; however, the daily mean temperatures in its urban areas may range from 8 °C in winter to 33 °C in summer, and hourly temperatures generally range from 5 to 38 °C. So common are high summertime temperatures, nearly 93% of Taiwan's residents have air conditioning in their home to alleviate the discomfort that comes with summer heat (Liao et al., 2016). In Taiwan, ambient air pollution inversely correlates with temperature, with some pollutant levels being much higher on cold days than on hot ones (Environmental Protection Administration, 2019). The interaction between temperature and pollution has not been adequately assessed in terms of hourly ambulance dispatches use. The current study analyzes island-wide city and county-specific hourly data to evaluate the hourly lag response and overall risk of using ambulance dispatches to treat respiratory distress, coma and unconsciousness, and OHCA, while bearing in mind ambient temperature, fine particulate matter of 2.5 μm ($PM_{2.5}$), and ozone (O_3).

2. Materials and methods

2.1. Data sources

We obtained ambulance dispatches data for Taiwan Island, excluding Taipei and New Taipei City, from the Ministry of Health and Welfare for the 2006–2015 period. Information and privacy protections pertaining to the ambulance dispatches database have been previously described (Wang et al., 2020). We extracted the hourly ambulance dispatches records of cases diagnosed with respiratory distress, coma and unconsciousness, or nonaccidental OHCA in 15 cities and counties. We analyzed hourly area cause-specific numbers for these events to determine their association with ambient environmental conditions.

Hourly meteorological data—including hourly average temperature (°C), relative humidity (%), wind speed (m/s), and barometric pressure (mb/hPa)—monitored at 25 real-time surface meteorological observatories around Taiwan were provided by the Taiwan Central Weather Bureau. For areas lacking observatory stations (e.g., Taoyuan, Miaoli, Changhua, Yunlin, and Nantou), weather data were obtained from the nearest surface meteorological observatory (Fig. 1).

Hourly $PM_{2.5}$ and O_3 data from 2006 to 2015, gathered at 76 stationary monitoring stations distributed throughout the island (Fig. 1), were obtained from the Taiwan Air Quality Monitoring Network. Detailed information on the monitoring instruments, stations, and quality assurance criteria is available on the Taiwan Environmental Protection Administration webpage (https://taqm.epa.gov.tw/taqm/en/default.aspx).

2.2. Statistical models

2.2.1. Area specific non-linear risk association

We adopted the distributed lag nonlinear model (DLNM) with a quasi-Poisson function, as proposed by Gasparrini et al. (2010), to assess the time-series nonlinear exposure–response relationship between the hourly ambient environment and the cause-specific number of ambulance dispatches. This was calculated thus:

$$\begin{aligned}\mathbf{Log[Y]} \sim \mathbf{BS(T, lag = 0-180\ hours)} \\ + \mathbf{BS(PM_{2.5}\ or\ O_3, lag = 0-120\ hours)} \\ + \mathbf{NS(time, 7\ per\ year) + +NS(hod, 4) + NS(ws, 5)} \\ + \mathbf{NS(rh, 4) + holiday\ effect + dow + PI}\end{aligned} \tag{1}$$

Here, *Y* is the number of times ambulance dispatches were used, on area–cause-specific and hourly bases; *T* is the area-specific hourly mean temperature. We used the B-splines (*BS*) function with two equal knots for hourly average temperature and two knots for lag response to estimate the delayed temperature–health risk association. We evaluated and presented the lag effects for 0–180 h at the mean island-wide temperature and the area-specific 5th and 99th percentiles, with the reference temperature set at 25 °C.

We included in the model hourly $PM_{2.5}$ and O_3 concentrations, separately; these were set as *BS* functions with two equal knots for air pollutant measurements and lag effect evaluation. We evaluated and presented the lag effects for 0–120 h with the island-wide and area-specific reference concentration set at as per Q1 data, at mean concentrations of the corresponding 90th percentile of measurements.

We included in the model the hourly wind speed (ws) and relative humidity (rh) and set the natural spline (*NS*) function with 5 and 4 d*f*, respectively. Note also our use of day of the week (dow) and the hour of a day (hod). We also included in the model, as confounding factors, daily deaths from pneumonia and influenza (PI). Model selection was based on the lowest Akaike information criterion (AIC) value (Gasparrini et al., 2017; Portet, 2020).

2.2.2. Meta-analysis

We adopted multivariate meta-analysis to estimate the cause-specific integrated relative risks for the whole of Taiwan, using the area–cause-specific risk of ambulance dispatches associated with temperature and $PM_{2.5}$ and O_3 concentrations. The meta-analysis was fitted using a random-effects model with maximum likelihood (Viechtbauer, 2010). The overall relative risk (RR) and related 95% confidence interval (CI) of area–cause-specific ambulance dispatches associated with temperature were estimated by controlling for $PM_{2.5}$ concentrations, as the reference temperature had been set to the temperature with the least risk of cause-specific ambulance calls. We also estimated the risk of ambulance dispatches in association with hourly $PM_{2.5}$ and O_3 concentrations, after controlling for temperature; we did so by accumulating for lag 0–96 h after a lag effect evaluation.

We executed all analyses using *the mgcv*, *dlnm*, and *mvmeta* packages in R (version 3.6.1).

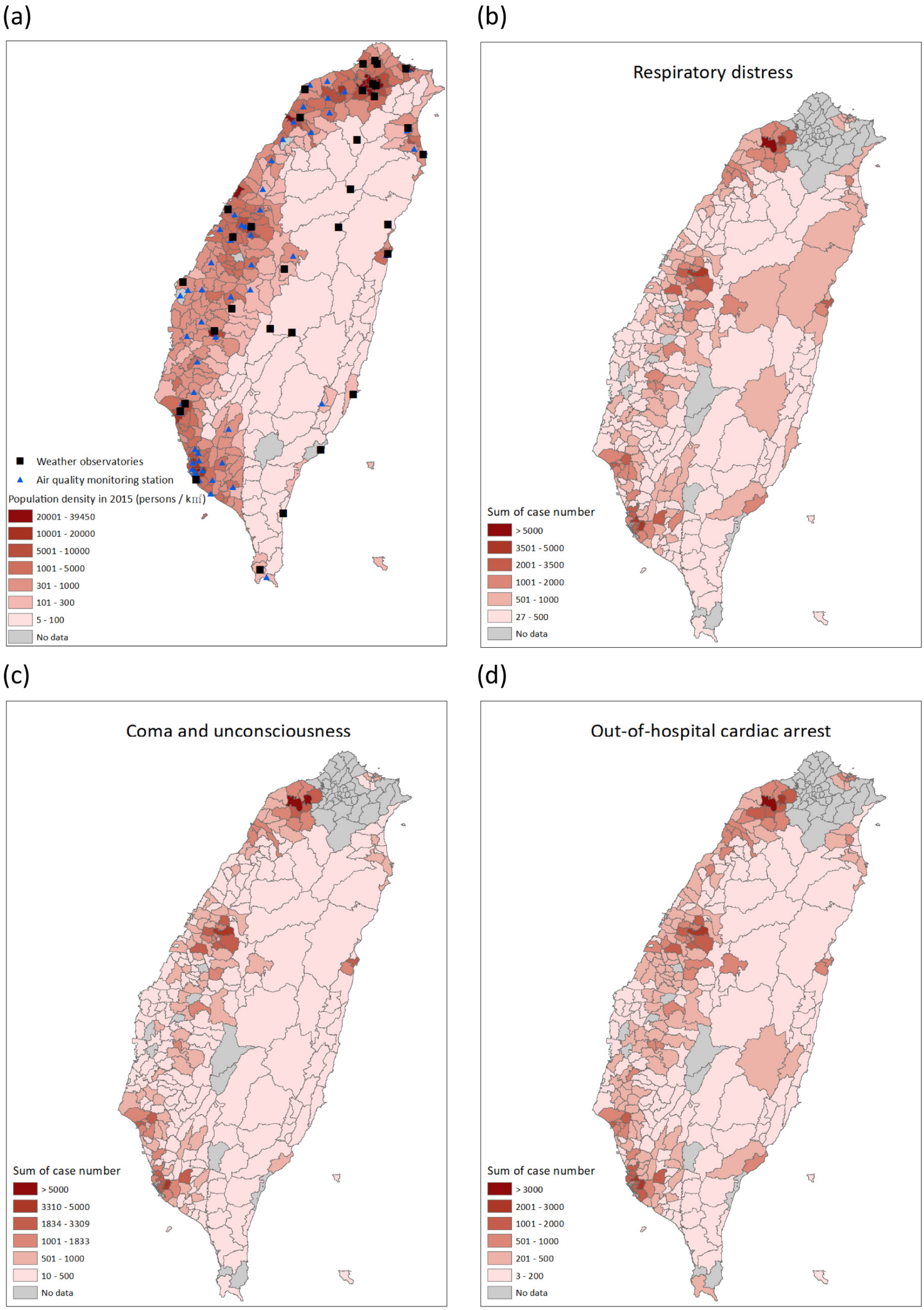

Fig. 1. (a) Locations of weather observatories and ambient air quality monitoring stations and district-level population density in 2015; and sum of case number of (b) respiratory distress, (c) coma and unconsciousness, and (d) out-of-hospital cardiac arrest from 2006 to 2015.

3. Results

3.1. Descriptive characteristics of ambient environment and ambulance dispatches, 2006–2015

Taiwan's estimated island-wide hourly mean temperature in the 2006–2015 period was 23.4 °C (range: 8.99–34.2 °C), with a mean $PM_{2.5}$ concentration of 29.6 μg/m^3 (range: 3.15–161 μg/m^3) and O_3 concentration of 29.4 ppb (range: 0.90–101 ppb) (Table 1). Overall, ambulance dispatches provided during this period saw to 238,937 cases of respiratory distress, 202,389 cases of coma or unconsciousness, and 117,488 cases of OHCA.

Fig. 1 shows the district-level population density and numbers of cause-specific ambulance dispatches. The cities of Kaohsiung, Taichung, and Tainan had the highest numbers of ambulance attendance. Fig. 2 shows the cause-specific disorders that used ambulance dispatches over the whole population of Taiwan, by hour of a day. In general, the number of daily cases was lower in the early morning (i.e., from 2 AM to 6 AM) and higher in the morning (i.e., from 8 AM to 9 AM) and in the evening (i.e., from 6 PM to 7 PM), save for ambulance services given in response to respiratory distress.

3.2. Lag association between hourly ambient temperature and levels of $PM_{2.5}$ and O_3 levels, and ambulance dispatches

Fig. 3 shows, with the reference temperature set at 25 °C, the overall lag association (lag 0–180 h) between cause-specific ambulance dispatches and the 5th and 99th percentile of island-wide hourly temperature (15 °C and 32 °C, respectively). Supplementary Figs. S1–S2 show risk patterns of extremely low (10 °C and 12 °C) and high (36 °C and 38 °C) hourly temperatures; moreover, Supplementary Figs. S3–S5 show area-specific lag associations. When it was cold, the risk of ambulance use peaked at lag 0–2 h for respiratory distress and coma and unconsciousness, and at lag 180 h for OHCA (Fig. 3). In a high-temperature environment, the risk of ambulance dispatches generally peaked at lag 16–18 h, with excess risk of 0.11% (95% CI; 0.06, 0.17) for coma and unconsciousness and 0.06% (95% CI; 0.01, 0.11) for OHCA (Fig. 3).

Fig. 4 illustrates the overall lag association between cause-specific ambulance dispatches and island-wide 90th percentiles of hourly $PM_{2.5}$ (49.1 μg/m^3) and O_3 (52.3 ppb) concentrations at lag 0–120 h, by setting the reference concentrations to those of the corresponding Q1. The area-specific lag associations are shown in Supplementary Figs. S6–S8. In general, the risk of ambulance dispatches associated with ambient O_3 concentration peaked at lag 14 h with a significant excess risk of 0.17% (95% CI; 0.11, 0.23) for respiratory distress, 0.11% (95% CI; 0.06, 0.16) for coma and unconsciousness, and 0.07% (95% CI; 0.01, 0.14) for OHCA (Fig. 4). For respiratory distress, we also saw an immediate (lag 0 h) but nonsignificant effect for $PM_{2.5}$.

3.3. Cumulative relative risk of ambulance dispatches associated with ambient temperature and levels of $PM_{2.5}$ and O_3 levels

Fig. 5 shows the cumulative 0–96-h effects of temperature on cause-specific ambulance dispatches. We found that the reference temperatures leading to the lowest risk of ambulance dispatces in Taiwan for respiratory distress, coma and unconsciousness, and OHCA were 28 °C, 20 °C, and 26 °C, respectively. With exposure to the 5th-percentile extreme temperature, the RR was 1.04 (95% CI; 0.98, 1.11) for respiratory distress, 1.02 (95% CI; 0.97, 1.08) for coma and unconsciousness, and 1.27 (95% CI; 1.19, 1.35) for OHCA. With exposure to the 99th-percentile extreme temperature, the RRs were 1.06 (95% CI; 0.97, 1.15) for respiratory distress, 1.17 (95% CI; 1.08, 1.27) for coma and unconsciousness, and 1.25 (95% CI; 1.11, 1.41) for OHCA.

Fig. 6 shows the cumulative 0–96-h relative risk of cause-specific ambulance dispatches associated with hourly $PM_{2.5}$ and O_3 concentrations, relative to Q1 levels. Cause-specific ambulance dispatches was not found to significantly correlate with hourly $PM_{2.5}$ and O_3 levels.

4. Discussion

There is a scarcity of hourly data on health events, and this has led to a dearth of research evaluating how health events correlate with hourly ambient environmental conditions (Ai et al., 2019; Chen et al., 2019; Cui et al., 2020; Xu et al., 2019). Among the health data, ambulance dispatches data are documented in terms of the time when urgent health events occur. These events can be identified in terms of time of day and analyzed in tandem with hourly records on ambient temperature and air-pollutant levels.

We evaluated the effects of the hourly ambient environment on ambulance dispatches for respiratory distress, coma and unconsciousness, and OHCA at lag 0–180 h in Taiwan. We identified the significant immediate impacts of extreme heat, at around lag 6–60 h, on ambulance dispatches for coma and unconsciousness and OHCA; the impacts of hourly extreme cold, on the other hand, were not significant. In addition, all ambulance service calls occurred whenever there were high concentrations of hourly O_3, at about lag 6–42 h. The overall RR of ambulance dispatches, accumulating for 0–96 h, was higher in association with an extremely high temperature (32 °C) than with an extremely cold one (<15 °C) (Fig. 5). Moreover, we found $PM_{2.5}$ and O_3 levels to have no significant effect on ambulance dispatches at the 90th percentile of measurement (Fig. 6).

In this study, we selected three types of urgent causes requiring ambulance dispatches, to assess any correlation between this use and ambient conditions. We selected respiratory distress, given its potentially life-threatening nature (Meghoo et al., 2019); additionally, coma and unconsciousness are events with a high proportion of emergency medical service use (Park et al., 2016). Meanwhile, a US study revealed that 60% of all emergency medical service use in that country were for OHCA (El Sayed et al., 2017), and so we also selected this condition. Among all-cause ambulance dispatches in Taiwan during the study period, respiratory distress accounted for 4.67%; coma and unconsciousness, for 3.95%; and OHCA, for only 2.29%.

Temperature-associated health risk varies by region and with the health disorder in question (Lin et al., 2019). Studies have assessed hourly ambulance calls in tandem with hourly ambient environmental variability (Ai et al., 2019; Alessandrini et al., 2011; Chen et al., 2019; Cheng et al., 2016; Cui et al., 2020; Guo, 2017; Niu et al., 2016; Onozuka and Hagihara, 2016; Wang et al., 2020). There are reports of elevated numbers of ambulance calls in relation to higher temperatures, and these reports use daily temperatures in Emilia-Romagna, Italy (Alessandrini et al., 2011), Brisbane, Australia (Guo, 2017), Taiwan (Wang et al., 2020), and Huainan and Luoyang, China (Cheng et al., 2016; Cui et al., 2020). Heat-related risk is typically seen when the daily temperature exceeds 27 °C (Alessandrini et al., 2011; Guo, 2017; Wang et al., 2020). However, there are no consistent findings with regard to the cold threshold (Lai and Wong, 2015; Wang et al., 2020). Several studies found that the impact of heat waves is immediate, and last for 24 h. In Brisbane, for example, hourly heat in excess of 27 °C could immediately increase the demand for ambulance use, and this spike can last for 24 h (Guo, 2017).

In Luoyang, China, ambulance calls in response to cardiovascular disease increase with temperature and reach a peak at extremely high temperatures (>32.1 °C) at lag 0–9 h (Cui et al., 2020). In contrast, we found delayed effects from low temperatures after a 48-h lag, and this finding aligns with those in Luoyang (Cui et al., 2020) and London (Sangkharat et al., 2020). Low temperature may increase blood viscosity, plasma viscosity, arterial pressure, and plasma cholesterol concentration, thereby intensifying stress on the cardiovascular system (Keatinge et al., 1984). A study in Suzhou, China reports that low temperature elevates blood pressure at lag 0–5 h, and that the pulse

Table 1
Descriptive table for hourly measurements of ambient environment and sum of cause-specific ambulance dispatches from 2006 to 2015 by city and county in Taiwan.

	Taiwan*	Keelung	Taoyuan	Hsinchu	Miaoli	Taichung	Nantou	Changhua	Yunlin	Chiayi	Tainan	Kaohsiung	Pingtung	Yilan	Hualien	Taitung
Ambient temperature (°C)																
Mean	23.4	22.4	22.9	22.9	22.9	23.4	19.3	23.1	23.7	23.7	24.5	25.5	25.5	22.8	23.6	24.6
Min.	10.5	8.09	8.02	8.02	8.02	9.34	7.13	9.00	10.2	10.2	10.7	13.2	15.5	8.90	11.7	13.4
P5	15.0	13.4	13.0	13.0	13.0	13.9	11.8	13.6	13.7	13.7	14.9	17.1	19.2	13.9	15.9	17.5
Q1	19.7	18.4	18.3	18.3	18.3	19.2	16.9	18.6	19.8	19.8	20.9	22.7	23.2	19.0	20.3	21.8
Med.	24.3	22.9	23.7	23.7	23.7	24.5	20.2	24.1	24.7	24.7	25.8	26.5	26.2	23.2	24.1	25.1
Q3	27.5	27.1	28.0	28.0	28.0	27.9	22.3	28.0	27.8	27.8	28.5	28.7	28.2	27.3	27.3	27.8
P99	32.3	31.7	33.4	33.4	33.4	32.4	28.1	31.9	33.6	33.6	33.1	32.8	32.3	32.2	32.2	32.4
Max	34.2	34.5	38.8	38.8	38.8	34.6	33.0	34.6	36.6	36.6	35.5	36.9	34.7	35.7	36.1	35.7
S.D.	4.92	5.24	5.88	5.88	5.88	5.41	4.19	5.49	5.58	5.58	5.22	4.35	3.58	5.21	4.53	4.07
Fine particulate matter (μg/m^3)																
Mean	29.6	20.6	26.2	27.4	28.1	32.4	36.2	35.0	37.3	36.7	36.1	40.5	30.9	20.0	19.5	13.7
Min.	3.15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q1	18.3	11.0	14.3	14.5	14.5	17.6	18.0	20.0	20.5	19.7	19.5	20.9	17.0	10.0	11.0	7.0
Med.	26.7	17.0	21.3	22.3	23.5	28.0	32.5	30.5	33.0	32.3	32.3	37.4	28.7	16.0	16.0	11.0
Q3	37.7	27.0	33.0	35.3	36.5	42.6	49.0	46.0	50.0	48.7	48.0	55.0	41.7	24.5	24.0	17.0
P90	49.1	38.0	47.3	49.7	50.5	58.6	66.0	62.5	66.5	66.7	64.8	72.1	52.7	35.0	34.0	26.0
P99	75.7	68.0	80.3	85.8	85.0	94.3	104	101	105	104	101	108	79.8	66.5	59.0	48.0
Max.	161	243	177	184	187	234	304	226	262	209	191	203	152	165	152	210
S.D.	15.1	14.2	42.2	22.7	27.5	20.4	28.7	20.8	22.3	22.5	21.4	23.8	19.5	28.8	27.9	19.9
Ozone (ppb)																
Mean	29.4	30.6	29.2	30.2	30.2	28.6	27.9	28.5	29.9	30.2	30.6	30.2	34.3	27.5	24.0	29.5
Min.	0.90	0.10	1.17	0.60	0.25	0.80	0.10	0.20	0.30	0.23	0.30	0.30	0.75	0.50	0.10	0.60
Q1	17.3	14.2	16.3	16.0	17.0	12.9	8.80	14.0	14.2	14.7	13.9	12.3	19.9	16.0	16.0	19.0
Med.	26.2	32.0	28.3	29.0	27.3	23.9	19.5	25.4	25.0	25.3	24.9	22.9	29.3	34.4	22.0	29.0
Q3	38.4	43.0	39.3	40.7	40.0	39.0	40.2	38.5	40.2	40.7	42.2	42.6	45.0	37.5	33.0	39.0
P90	52.3	53.5	50.8	53.0	54.2	57.6	66.4	54.5	60.9	61.1	64.0	66.9	62.7	46.7	43.0	47.0
P99	73.9	77.0	76.3	82.7	85.5	91.5	101	86.0	92.6	92.0	92.0	95.6	87.7	64.5	60.5	62.0
Max.	101	308	122	131	164	146	201	140	141	166	149	151	162	119	110	106
S.D.	15.7	18.4	16.5	17.9	17.9	20.3	24.8	18.9	20.8	20.8	22.0	23.2	19.0	14.4	13.7	13.5
Sum of ambulance dispatches from 2006 to 2015																
Respiratory distress	238,937	5248	26,027	11,460	6843	34,189	9143	16,331	9280	13,018	32,084	38,391	13,785	7898	8801	6439
Coma and unconsciousness	202,389	3258	26,388	11,644	5675	31,182	6260	14,876	9562	10,295	27,745	32,380	10,026	4513	6565	2020
Out-of-hospital cardiac arrest	117,488	3378	14,679	6625	3934	17,219	3654	8976	4407	5715	13,695	20,454	6194	3010	3079	2469

* The statistics of temperature are calculated from measurements of observatories located in Taiwan Island, excluded Taipei, New Taipei City, and Nantou (elevation is 1020 m).

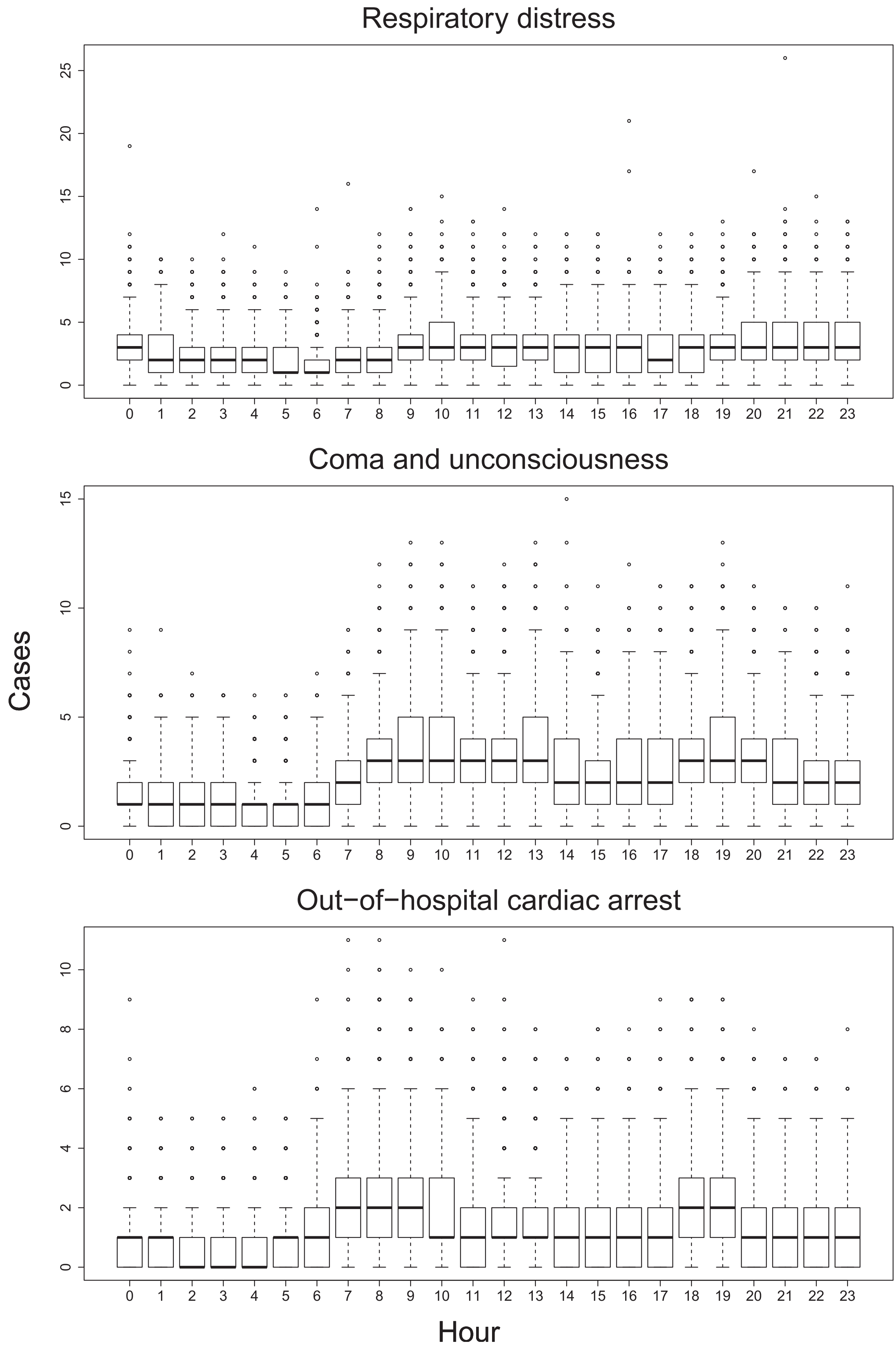

Fig. 2. Hourly cause-specific cases calling for ambulance dispatches from 2006 to 2015.

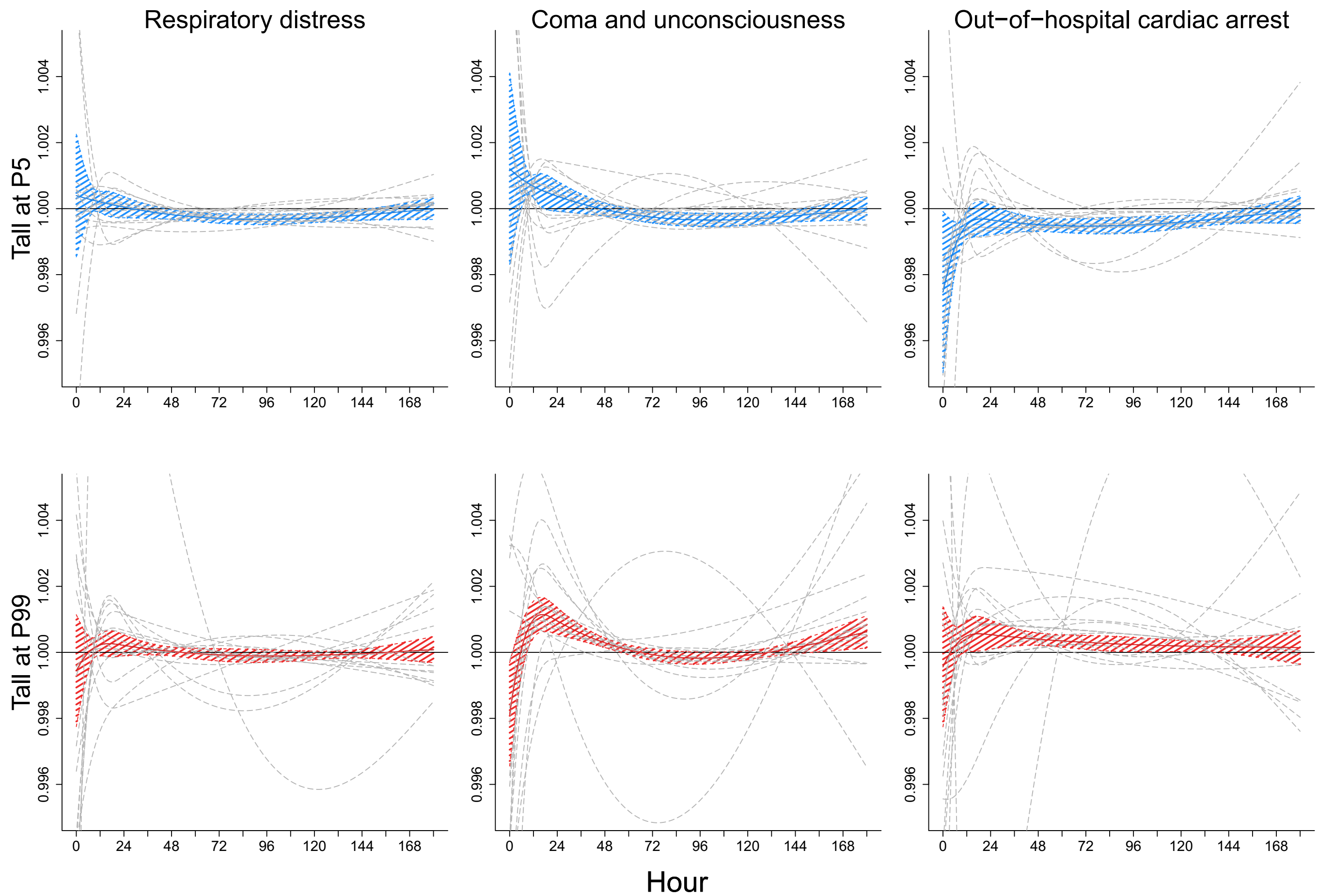

Fig. 3. Pooled relative risks of ambulance dispatches associated with extreme low (5th percentile (P5), 15 °C) and high (99th percentile (P99), 32 °C) temperatures along with lag hours (0–180 h) with reference temperature at 25 °C.

pressure of the diabetic population is particularly sensitive to heat (Xu et al., 2019).

The occurrence of OHCA can be attributed to extreme temperatures. Studies in Guangzhou, China and Taiwan report that OHCA risk increases on both cold and hot days, and when plotted assumes a J or V-shaped relationship (Niu et al., 2016; Wang et al., 2020). A Japanese study examining 10,723 OHCA cases found not only ambient temperature but also certain activities to correlate with incidents (Nishiyama et al., 2011): on cold days, OHCA incidence was found to be 8.8-fold greater when bathing than when sleeping. In fact, when bathing, the risk significantly increased to six-fold greater at ≤5 °C than at ≥25.1 °C. In addition to OHCA, other types of ambulance events in Taiwan—including those responding to respiratory distress, coma, and unconsciousness—also correlate with daily ambient temperature (Wang et al., 2020). Overall, people living in warm climates are generally more vulnerable to cold days than to hot days (Yang et al., 2018).

The risk of OHCA has also been found to correlate with air pollution levels, although there is no consensus. A study in Houston, Texas assessing 11,677 OHCA cases showed that ozone levels correlate with an immediate risk (i.e., a few hours of or same-day exposure to ozone prior to OHCA), while an increase in $PM_{2.5}$ levels was associated with risk with a two-day lag (Ensor et al., 2013). In Japan, particulate matter was found to significantly increase emergency ambulance dispatches at a 0–1-day lag (Tasmin et al., 2016), and at lag 0 in each of Chengdu, China (Liu et al., 2017) and Sydney, Australia (Salimi et al., 2017). A recent study conducted in a central city in China reported that the risk of acute-condition ambulance calls were associated with air pollutant exposure at a lag of 0–72 h, and that this varies with the prompting health condition and the type of air pollutant; exposure to $PM_{2.5}$, for example, was found to correlate with an excess risk of 0.19% (Ai et al., 2019). Another study, in Shenzhen, China, found that a 10-μg/m^3 $PM_{2.5}$ incremental increase correlated with a 0.72% increase in emergency department visits at lag 0–10 h (Chen et al., 2019), while a study in six cities in the Pearl River Delta region of China also reported that the 10 μg/m^3 $PM_{2.5}$ increment corresponded to 1.2% increase in cardiovascular mortality and a 0.7% increase in respiratory mortality (Lin et al., 2017). A systemic study found that the risk of OHCA increased after exposure to both $PM_{2.5}$ and ozone; additionally, the risk was higher for ozone (within 3 h) than for $PM_{2.5}$ (within 0–4 days) (Teng et al., 2014). We found that O_3 was a strong risk factor associated with ambulance calls, with a 6–42-h lag; also, we found that the high hourly $PM_{2.5}$ concentration (49.1 μg/m^3) did not significantly correlate with ambulance calls at lag 0–120 h (Figs. 4 and 6). A recent study in China found that $PM_{2.5}$ correlates with increased mortality and lost years of life, with both short and long-term exposure (Qi et al., 2020).

Our previous study based on daily data shows that, overall, ambulance use correlates with low temperature (≤15 °C), but that use for coma and unconsciousness and for OHCA tends to correlate with high temperature (≥31 °C) (Wang et al., 2020). Moreover, an extremely high daily concentration of $PM_{2.5}$ (about 90 μg/m^3) significantly elevates the need for ambulance care for respiratory distress and OHCA. On the other hand, the present study is based on hourly time-span analysis, and while we found a reduced risk with low hourly temperatures, there was an increased risk with hourly heat exposure. Additionally, the significant relationship seen with the daily mean $PM_{2.5}$ levels did not hold with the hourly $PM_{2.5}$ level. The temperature and $PM_{2.5}$ and O_3

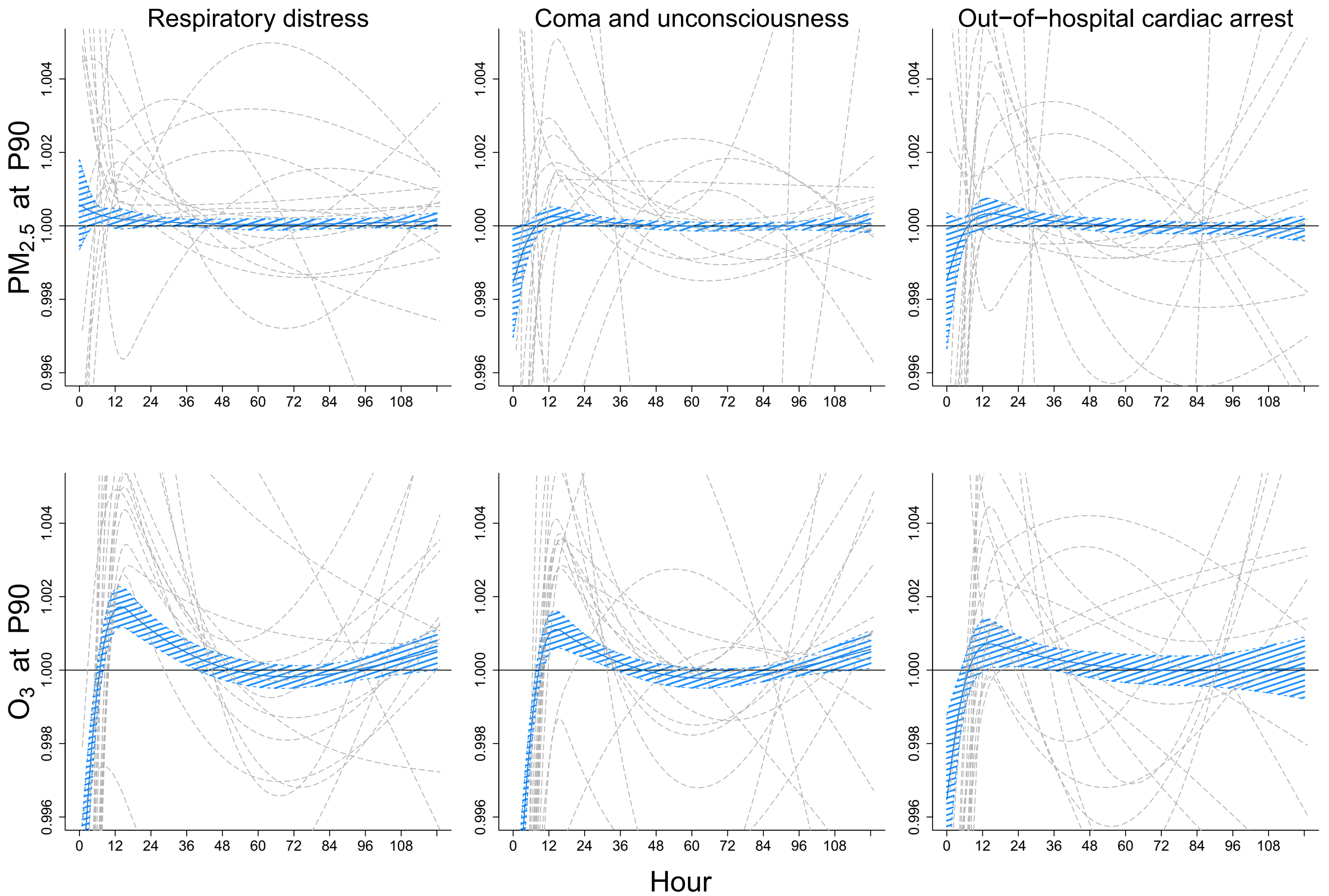

Fig. 4. Pooled relative risks of ambulance dispatches associated with $PM_{2.5}$ and O_3 concnetrations at island-wide 90th percentile (P90) along with lag hours (0—120 h) with reference concentration at Q1 measurements.

concentrations varied over the day, hour by hour. Unlike daily ambient environment–health association analysis, hourly association analysis speaks to an immediate and real-time response rather than a longer-term relationship. Furthermore, for the same ambient environment measurements, the exposure level to daily average temperature and $PM_{2.5}$ and O_3 levels were much higher than those measured on an hourly basis. Future research needs to differentiate the impact of daily versus hourly exposure to the ambient environment, especially when such data are used in early warning systems.

The present study has several strengths and makes contributions to the literature. We used a large body of hourly data captured by the Taiwan ambulance services program, and another dataset pertaining to ambient air quality data, to ensure representative exposure for the entire population. We considered certain confounders—such as the

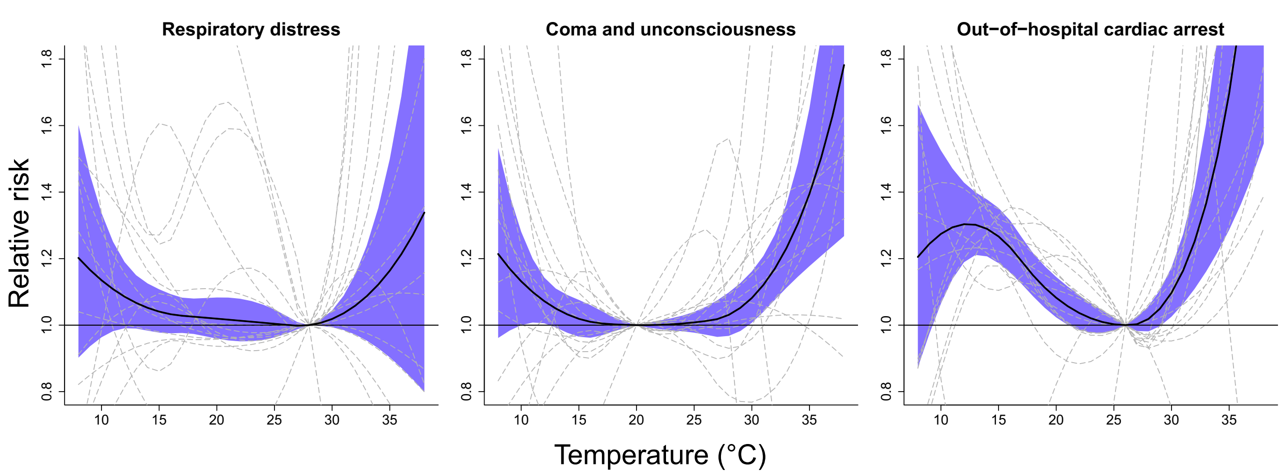

Fig. 5. Pooled cumulative-96 h risks of ambulance dispatches associated with ambient temperatures.

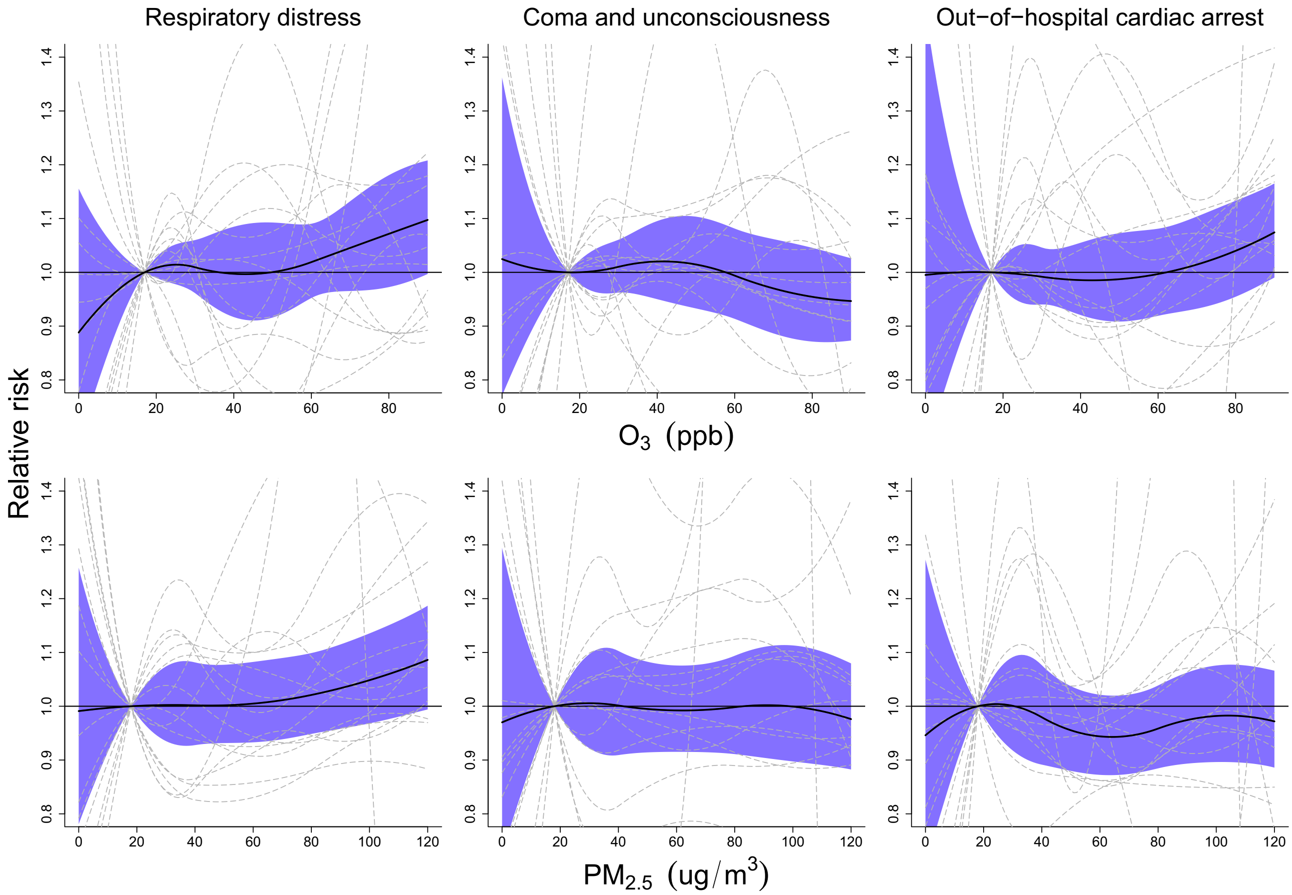

Fig. 6. Pooled cumulative-96 h risks of ambulance dispatches associated with hourly $PM_{2.5}$ and O_3 concentrations.

holiday effect, day of the week, hour of the day, long-term trends, and risk associated with infectious pneumonia and influenza—in our data analysis models. Additionally, our data can be used to analyze ambulance dispatches associated with ambient characteristics, in terms of sex, age, and region; in this way our data and methodology can be used to identify vulnerable subpopulations and inform policy that improves the lives of individuals therein (Alessandrini et al., 2011).

This study, like any study, has limitations. First, this is an ecological study, and it does not estimate risk by leveraging individual-level data. There were other so-called holes in the data we used: information on disease history, medication use, lifestyle, and accessibility to medical services was unavailable in the data we used, and so we were unable to control for these potential confounders in our data analyses. Patient diagnoses in the medical records of ambulance dispatches were based on observations made by medical personnel, and no ICD codes were provided. Moreover, ambulance emergency calls can be attributed to complicated conditions, such as delayed arrivals, restricted service times, and inaccessible locations. These limitations may alter risk estimations.

5. Conclusions

The pooled risks for study ambulance dispatches in Taiwan over the 2006–2015 period peaked at lag 16–18 h when the population was exposed to the 99th percentile of island-wide hourly temperature, and at lag 14 h with exposure to high hourly O_3 levels. The cumulative 0–96-h relative risk in association with extremely high and low temperatures was highest for ambulance dispatches relating to OHCA. No significant cumulative 0–96-h risk was identified for hourly $PM_{2.5}$ and O_3 levels. Clearly, an hourly lag differs quantitatively from daily ones; thus, we recommend future comparative research of daily versus hourly association. The current study provides health authorities with critical information they can use to develop future ambulance service plans in the face of rapidly changing atmospheric environments.

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CRediT authorship contribution statement

All authors were involved in designing the study, YCW and YKL drafted the manuscript, YJC, CPC and YCW analyzed the data, and YCW, FCS and YKL finalized the manuscript. All have read and approved the final version of the manuscript.

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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