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Hourly associations between heat and ambulance calls☆

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ABSTRACT

Background: The response speed of ambulance calls is very crucial to rescue patients suffering immediately life threatening conditions. The serious health outcomes might be caused by exposing to extreme heat only several hours before. However, limited evidence is available on this topic. This study aims to examine the hourly association between heat and ambulance calls, to improve the ambulance services and to better protect health.
Methods: Hourly data on ambulance calls for non-accidental causes, temperature and air pollutants (PM_{10}, NO_2, and O_3) were collected from Brisbane, Australia, during 2001 and 2007. A time-stratified case-crossover design was used to examine the associations between hourly ambulance calls and temperature during warm season (Nov, Dec, Jan, Feb, and Mar), while adjusting for potential confounders. Stratified analyses were performed for sex and age groups.
Results: Ambulance calls peaked at 10am for all groups, except those aged <15 years at 19pm, while temperature was hottest at 13pm. The hourly heat-ambulance calls relationships were non-linear for all groups, with thresholds between 27 °C and 31 °C. The associations appeared immediately, and lasted for about 24 h. There were no significant modification effect by sex and age.
Conclusions: The findings suggest that hot hourly temperatures (>27 °C) increase the demands of ambulance. This information is helpful to increase the efficiency of ambulance service then save lives, for example, preparing more ambulance before appearance of extremely hot temperature in combination with weather forecast. Also, people should better arrange their time for outdoor activities to avoid exposing to extreme hot temperatures.

1. Introduction

There has been increasing interests in assessing the impacts of heat on human health, as climate change will increase the global mean temperature, and increase the frequency, duration, and intensity of heatwaves (Moss et al., 2010). Understanding heat-related health issues is important for development of public health policy and improvement of health services that seeks to minimise the adverse health impacts of extreme hot temperatures (Huang et al., 2013). To date, many studies have examined the heat effects on mortality/morbidity (hospital admission and emergency hospital visits) in different cities/regions/countries, with daily time series data (Gasparrini et al., 2015; Guo et al., 2014; Ye et al., 2012). Such kind studies have played an important role to understand the heat effects on health and to develop public policies regarding health protection. However, using daily data might miss the very short-term heat effects (exposure within few hours) (Bhaskaran et al., 2011). There is no doubt that assessment of the hourly heat effects on health outcomes can be used for improvement of public health or clinical guidelines, but limited evidence is available due to limited hourly health data (Bhaskaran et al., 2012).

Data on ambulance calls (including information of calling time) is a good candidate to examine the hourly heat-health associations (Yorifuji et al., 2014). There are lots of benefits from assessing hourly heat impacts on ambulance calls, from the ability to conduct more targeted health intervention strategies, to the development of precise early heat-warning systems (Bassil et al., 2008). Importantly, it is helpful to increase the response speed of ambulance calls which is very crucial to rescue patients suffering immediately life threatening conditions (Thornes et al., 2014). However, no study has examined the hourly associations between heat and ambulance calls, although some studies show daily hot temperatures increase rates of daily ambulance attendances (Turner et al., 2012; Wong

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and Lai, 2014).

2. Material and methods

This study was conducted in Brisbane, the capital city of Queensland, Australia. Brisbane is located on the east coast of Australia (27° 30′ south and 153° 00′ east), and has a subtropical climate and generally experiences mild winters and hot summers.

2.1. Data on ambulance calls

Data on ambulance attendance were collected from the Queensland Ambulance Service during 2001 and 2007. Queensland Ambulance Service is the main provider of ambulance transport and out-of-hospital emergency in Brisbane. Only data on Australian citizens and permanent residents were used in this study. The data extracted from each anonymised attendance record include the time of ambulance calls (including hour and date), sex and age of the patient, and the health assessment of the patient recorded using the 10th revision of International Classification of Diseases (ICD10). Ethical approval was obtained prior to the collection of these data.

In this study, ambulance calls for non-accidental causes were extracted for analysis, as it is assumed that accidental attendance may be not related to ambient temperature exposure. To investigate effects of heat specifically, the analysis was restricted to the warm season (November, December, January, February, and March).

2.2. Environmental exposure data

Hourly meteorological data (temperature and humidity) and hourly data of concentrations of air pollutants [ozone (O_3), nitrogen dioxide (NO_2), and particulate matter of size <10 µm (PM_{10})] were obtained from the Department of Environment and Resource Management from eight monitoring sites throughout Brisbane during the study period. Hourly mean values were then calculated for all meteorological and environmental data; when a particular station had missing data, the average across the remaining stations was calculated.

2.3. Statistical analysis

A time-stratified case-crossover design was used to examine the associations between heat and ambulance calls. The case-crossover study is a type of self-matched case-control study (Maclure, 1991). For each individual, exposure information are collected for the "case" period and a series of "control" periods that were not associated with the event of interest. The case-crossover design was used to compare the individual's temperature exposure directly before his/her ambulance calls to the exposure at other times when he/she did not call ambulance. For the time-stratified case-crossover design, control periods should be selected from the fixed time strata as the source of control days, which avoids any "overlap bias" (Janes et al., 2005). In addition, by comparing exposure preceding the ambulance calls with exposure on hours shortly before and after the ambulance calls in the same time strata, the seasonal trends can be successfully controlled for.

In this study, the calendar month was used as fixed time strata and control periods comprised the same hour of the same day of the week in the calendar month of ambulance calls, to control for the effect of day of the week and intra-day variation (Fig. 1). The conditional logistic regression model was used to fit the time-stratified case-crossover design, which successfully controlled for time-invariant individual level confounders (e.g., smoking and weight), because comparisons between case and control periods

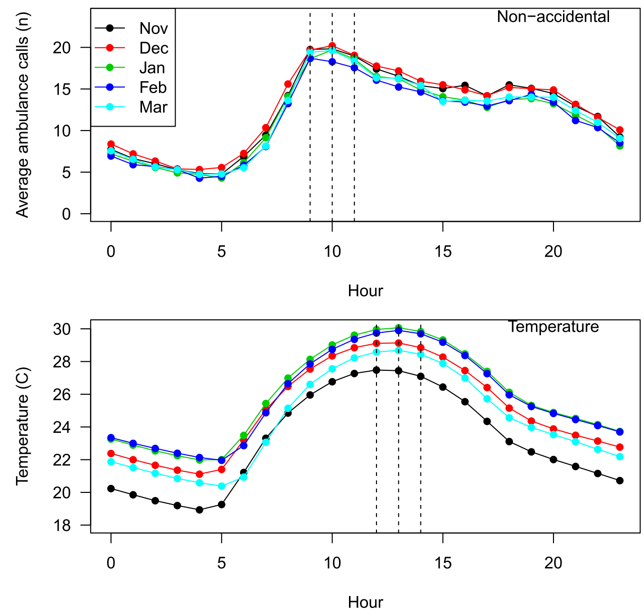

Fig. 1. The average hourly counts of ambulance calls for non-accidental causes and the average hourly temperature in five warm months (Nov, Dec, Jan, Feb, and Mar) in Brisbane, during 2001 and 2007.

were made within individuals. The association between ambient temperature and risk of ambulance calls was examined by using a distributed lag non-linear model (DLNM), allowing for delayed effects of up to 10 days (0–240 h). The reason for choosing lag periods of up to 10 days was to fully capture the potential lag period, as previous daily time series studies have observed heat mortality/morbidity associations lasted for 1–3 days (Guo et al., 2014). A nature cubic spline with 4 degrees of freedom was used for both temperature and lag hours, as the initial analysis showed it produced best model fit as judged by lowest value of Akaike Information Criterion (AIC). To fully adjust for the other potential time-variant confounders, PM_{10}, NO_2, O_3, and relative humidity were controlled in all models by natural cubic splines with 4 degrees of freedom for their 0–72 h mean values.

To assess the possible modification effects of demographic factors on the associations between heat and ambulance calls, stratified analyses were conducted for sex and age groups (<15, 15–34, 35–64, and ≥65 years). A meta-regression was used to test the statistical difference between effect estimates for subgroups (e.g., men VS women) (Li et al., 2016; Yang et al., 2015). For instance, the effect estimates of stratum-level analyses (e.g., men and women) were put as dependent variable in the meta-regression, while the predictor (men and women) were put as independent variable. The likelihood ratio test was used to examine whether the effect estimates between men and women were statistically different or not.

In order to better inform the public health policy and to improve the ambulance service, the thresholds of heat-ambulance calls associations were examined for each group. First, potential range of thresholds was visually checked by plotting the graph of the relationship between heat and ambulance calls. Then AIC values for conditional logistic regression models were iteratively examined by 1 °C increment in temperature within the identified range of thresholds using the segment spline model. The temperatures corresponding to the lowest AIC values were chosen as the thresholds. This method has been widely used to test thresholds in the temperature-mortality associations using daily time series data (Guo et al., 2011).

The relative risks and 95% confidence intervals (CIs) of ambulance calls at 99th percentile of temperature against 85th percentile of temperature was calculated to show the effects of extreme hot temperatures.

Sensitivity analyses were performed to check the robustness of the results. To check whether the effects of day of the week were fully controlled for, case and control periods were matched by the same hour of other days of the same week; this is also helpful to check any effect of residual autocorrelation on the results. Air pollutants were moved out the models to check if there is any change in the heat-ambulance calls associations.

All analyses were performed using R software (version 3.2.2). The “dlnm” package was used to fit DLNM (Gasparrini, 2011). Cox regression with “Breslow” ties was used to fit conditional logistic regression model for the time-stratified case-crossover design. Example R codes for fitting DLNM and conditional logistic regression are shown in Appendix EXAMPLERcode.

3. Results

There were 755,075 ambulance calls for non-accidental causes in the warm season during 2001 and 2007, including 52% female, 18.8% people aged <15 years, 31.3% people aged 15–34 years, 30.7% people aged 35–64 years, and 19.2% people aged ≥65 years (Table 1). The ambulance calls for non-accidental causes peaked at 10am for all groups, except those aged <15 years at 19pm (Fig. 1 and Fig. S1). The mean hourly temperature, relative humidity, PM_{10}, NO_2, O_3 were 24.8 °C, 70.3%, 18.3 μg/m^3, 4.9 ppb, and 16.1 ppb, respectively (Table 2). Hottest temperature peaked at 13pm (Fig. 1).

Fig. 2 shows the relative risks of ambulance calls for non-accidental causes associated with 99th percentile of temperature (33 °C) in comparison with 85th percentile of temperature (28.7 °C) along 0–240 h. The associations between temperature and ambulance calls appeared immediately and lasted for about 24 h. Similar associations were found for sex and age groups (results were not shown).

Fig. 3 shows the cumulative relative risks of ambulance calls for non-accidental causes associated with hourly temperature over 48 h. The association between temperature and ambulance calls was non-linear. Similar associations were found for sex and age groups (Fig. S2). The thresholds were 27 °C for ambulance calls for non-accidental causes, for female, for male and for those aged 35–64 years; 28 °C for people aged 15–34 years, and for those aged ≥65 years; and 31 °C for people aged <15 years.

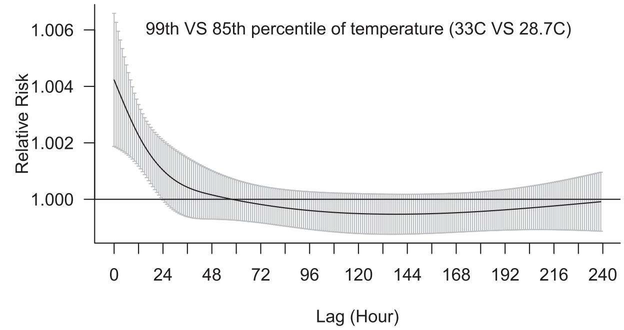

Fig. 2. The relative risks of ambulance calls for non-accidental causes associated with 99th percentile of temperature (33 °C) in comparison with 85th percentile of temperature (28.7 °C) along lags of 0–240 h. A natural cubic spline with four degrees of freedom was used for lags.

The cumulative relative risks of ambulance calls associated with 99th percentile of temperature (33 °C) in comparison with 85th percentile of temperature (28.7 °C) were 1.29 [95%CI: 1.15–1.45] for non-accidental causes, 1.39 [1.18–1.63] for female, 1.20 [1.02–1.41] for male, 1.04 [0.80–1.35] for people aged <15 years, 1.32 [1.07–1.62] for people aged 15–34 years, 1.33 [1.11–1.61] for people aged 35–64 years, and 1.41 [1.10–1.82] for those aged ≥65 years (Fig. 4). The modification effects by sex and age were not statistically significant.

Our main results were robust to match the case and control by the same hour of other days in the same week, and to remove air pollutants from the models.

4. Discussion

To the best of my knowledge, this study is the first to examine the associations between hourly temperature and ambulance calls. There were non-linear associations between temperature and ambulance calls after controlling for seasonality, day of the week, intraday variation, air pollution and relative humidity. The associations appeared immediately and lasted for about 24 h. The thresholds ranged from 27 °C to 31 °C. There were no significant modification effects by sex and age.

Ambulance calls peaked at 10am while hottest temperature peaked at 13pm. This phenomenon means that the hourly trend of ambulance calls is not only caused by temperature but also other impact factors for example physiological factors (e.g., high blood pressure and blood glucose in the morning) (Pickering et al., 2006) and behaviours (exposure to air pollution in the morning activity) (Grima et al., 2004). Thus it is necessary to control for such hourly trend in ambulance calls through matching case and control by the same hour.

It is well-documented that rapid ambulance response is very crucial to save life-threating health conditions. Many studies show that the shorter response time of ambulance, the higher survival rate for those calling ambulance (Brison et al., 1992; Cummins et al.,

Table 1
Counts and percentage of ambulance calls in Brisbane, during 2001 and 2007.

Group	Count (n)	Percentage (%)
All	755,075	100
Female	392,424	52.0
Male	362,606	48.0
Age <15	141,885	18.8
Age 15–34	236,348	31.3
Age 35–64	231,588	30.7
Age ≥65	145,254	19.2

Table 2
Statistical summary for hourly weather conditions and air pollutants in Brisbane, during 2001 and 2007.

Variable	1%	25%	50%	75%	85%	95%	99%	Mean	Standard deviation
Temperature (°C)	17.4	22.3	24.6	27.4	28.7	30.7	33.0	24.8	3.5
Relative humidity (%)	51.0	59.5	72.1	82.0	85.6	89.8	92.9	70.3	14.1
PM_{10} (μg/m^3)	13.0	15.0	17.4	20.2	22.1	26.8	38.7	18.3	5.9
NO_2 (ppb)	2.5	3.3	4.5	6.2	7.2	9.1	11.8	4.9	2.2
O_3 (ppb)	5.4	9.2	15.0	21.6	25.5	33.1	41.2	16.1	9.0

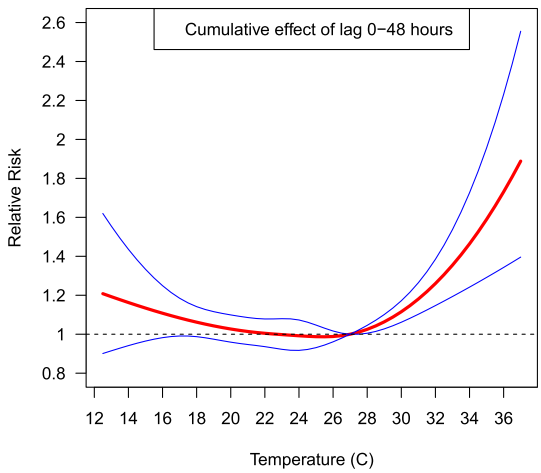

Fig. 3. The cumulative relative risks of ambulance calls for non-accidental causes associated with hourly temperatures over lags of 0–48 h. A natural cubic spline with four degrees of freedom was used for hourly temperature.

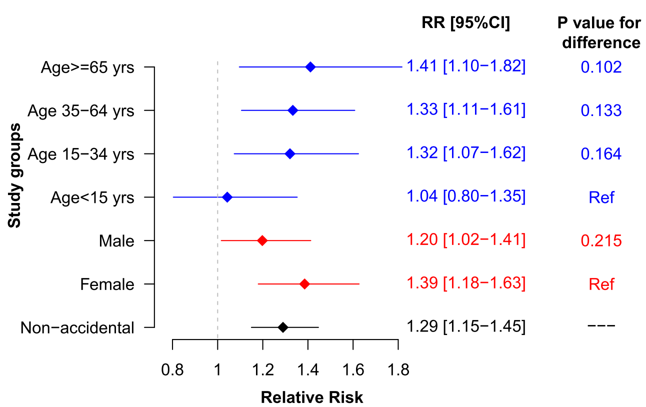

Fig. 4. The cumulative relative risks of ambulance calls for non-accidental causes associated with 99th percentile of temperature (33 °C) in comparison with 85th percentile of temperature (28.7 °C) over lags of 0–48 h for subgroups. The values were extracted from Fig. 3 and Fig. S2.

1991; Larsen et al., 1993). Understanding the hourly associations between temperature and ambulance calls is important to increase the efficiency of ambulance service and thus to save the life for patients with serious health conditions. In general, this study shows that hourly temperatures above 27 °C increased the rates of ambulance calls in warm season. This suggests that, to increase the response speed of the ambulance service, more ambulance should be allocated during the extreme hot hours.

This study shows that the lag effects of hourly temperature on ambulance calls should also be considered for ambulance preparation. Extreme high temperature is not only associated with the increased rate of ambulance call immediately, but also in the following 24 h approximately. This means ambulance service should not make light of the following hours after extreme high temperature. This lag pattern is consistent with a previous study on hourly association between heat and myocardial infarction onset in UK (Bhaskaran et al., 2012).

No previous study has examined hourly heat-ambulance calls associations, but few have been performed to examine the daily temperature-ambulance attendances associations (Turner et al., 2012; Wong and Lai, 2014). Those studies have reported a significant association between same-day heat and hospital admissions by ambulance (Makie et al., 2002). A daily time series study conducted in Brisbane also reported that heat effects were found to be acute and lasted within 0–1 days (Turner et al., 2012). These findings are consistent with the present study showing a 24-h lag effects. As extreme high temperatures appeared at around 13pm (Fig. 1), their effects could be lasted to the following day. Thus, the heat effects on ambulance calls could appear on the same day and the next day if the daily data was used.

Notably, the heat-ambulance calls association is a reflection for heat-related serious health conditions, as people usually call the ambulance just after the life threat. Thus, people should avoid to expose to hot temperatures >27 °C. In other words, keeping indoor temperature under 27 °C (using air conditioning or fan) is helpful to protect health (Nicol and Humphreys, 2002).

Importantly, the temperatures corresponding to minimum hourly ambulance calls (temperature thresholds) were identified between 27 °C and 31 °C for different groups. Understanding hourly temperature thresholds on ambulance calls is more beneficial for health intervention strategies, as they can be used to develop more precise early heat-warning systems than daily temperature thresholds (Bassil et al., 2008). It is helpful for development of public health policy and improvement of health services that seeks to minimise the adverse health impacts of extreme hot temperatures above these thresholds. Moreover, people should efficiently organise their outdoor activities according to these temperature thresholds, to better protect their health.

The temperature-ambulance calls associations were not statistically different for sex and age groups. This is not consistent with previous studies which show that children and the elderly are usually more vulnerable to heat-related health risks than adult, while women have a greater heat-related health risk than men (Ye et al., 2012). As this study is only from one city, more studies are still needed to test the difference in temperature-ambulance calls associations by sex, age groups and other modification factors.

This study has several strengths. This is the first study to date to examine the hourly associations between heat and rate of ambulance calls. The findings are very important to improve efficiency of ambulance service and to save lives. The time-stratified case-crossover design automatically controls for the intraday variation of ambulance calls and time invariant individual level factors, through matching case and control by time of day. This study also adjusted for other key confounders including seasonality, hourly pollution levels, and day of the week effects.

There are also some limitations of the study. Firstly, because the primary purpose of the ambulance data is for administrative and performance evaluation purposes, disease codes (ICD10) are not detailed as those in a hospital setting. The available coding for disease type was limited for ambulance attendances, and therefore, only are ambulance calls for non-accidental causes used in this study. Secondly, this study was based on the data on the time of ambulance calls, but symptom onset occurred before the calls. Thus, it should be cautious to translate the heat-ambulance calls associations to heat-symptoms relationships. Thirdly, as other studies in this field, the fixed monitoring exposure was used to replace the individual exposure. This measurement error is likely to bias the results towards the null, but a previous study found that using fixed monitoring data produced the same effect estimates as using spatial exposure data for the heat effects on morality (Guo et al., 2013).

5. Conclusions

Extremely hot hourly temperatures were associated with increased rate of ambulance calls. The effects lasted for about 24 h. The thresholds for the heat-ambulance calls ranged from 27 °C to 31 °C. The findings might be helpful to increase the response speed of the ambulance service, and thus save lives. In addition, people should better arrange their time for outdoor activities to avoid exposing to extreme hot temperatures.

Conflict of interest disclosures

None declared.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2016.10.091.

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