The Usefulness of Maximum Daily Temperatures Versus Defined Heatwave Periods in Assessing the Impact of Extreme Heat on ED Admissions for Chronic Conditions

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Abstract: *Objective*: To compare a heatwave based exposure classification with a maximum daily temperature based exposure classification in assessing the associations between increased heat and emergency department (ED) admissions for chronic conditions.

Methods: ED admission data was collected from 4 public hospitals in South Australia from 2007 to 2009. Effects of 5 heatwave periods were examined using conditional logistic regression (heatwave versus non-heatwave) whilst effects of maximum daily temperature were explored using negative binomial regression with temperature classified using <25 °C (reference category) and additional 5 °C increments. Non-linear regression (ED admissions per unit °C) was used to examine possible temperature thresholds for increased ED admissions.

Results: In heatwave/non-heatwave analysis, an increased odds of admission during heatwaves was observed for heat-related complaints [OR=3.2; 95%CI=2.5, 4.11] and renal conditions [OR=1.13; 95%CI=1.05, 1.21] only. In temperature based analysis, mental health related conditions began increasing at 30-34 °C compared to <25 °C [IRR=1.11; 95%CI=1.02, 1.20], heat related conditions were increased at 35-39 °C [IRR=3.4; 95%CI=2.48, 4.64] while CVD admissions were lower above 40 °C [IRR=0.89; 95%CI=0.80-0.99]. Significant threshold temperatures were identified for heat-related conditions at 37.6 °C [p<0.001] and for renal admissions at 39.2 °C [p<0.001].

Conclusions: Using maximum daily temperature was a more sensitive approach to detecting effects of heat on ED admissions for chronic disease and also allowed the detection of temperature threshold effects. Assessing the impact of temperature rather than heatwaves should better identify the weather conditions that increase the risk of events amongst individuals with specific chronic conditions.

Keywords: Emergency department admissions, excess heat, temperature threshold, chronic conditions, case-cross over design, conditional logistic regression, negative binomial regression.

INTRODUCTION

Increases in mortality during periods of extreme heat occur in both hot climates such as Australia [1-4] and more temperate climates such as the UK [5-7], Europe [8] and North America [9] where most of the increased mortality is due to extreme temperature. Due to the U-shaped nature of the mortality risk curve, most studies examining the effects of increased temperature on mortality have focused on using daily temperature measures such as the mean or maximum daily temperature as the exposure [7] rather than extreme temperature periods such as heatwave versus non-heatwave days [5]. Critical temperature thresholds for increased risk of mortality have also been examined [11, 12].

In comparison, the effects of higher temperatures on measures of heat related morbidities such as the number of hospital or emergency department (ED) admissions has been studied less often [13-15]. In addition, most hospital activity studies have focused on the increases in admissions between heatwave and non-heatwave periods rather than on the effects of daily temperature [16]. A limitation of this approach is that there is little consensus as to what defines a heatwave which can result in substantive differences in conclusions [16]. Another disadvantage is the lack of sensitivity since periods of very warm temperatures may potentially contribute to non-heatwave periods, and all temperatures above or below a defined limit are treated similarly.

Non-linear relationships have been observed in mortality studies using daily maximum temperatures to examine the effects of heat [10, 12, 17, 18], but the nature of the relationship between maximum temperature and morbidity (as opposed to mortality) has been investigated less thoroughly. Although some

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temperature-morbidity studies have examined whether linear threshold temperature effects exist, these studies have been in relation to total ED admissions rather than condition-specific ED admissions. For example, a linear increase in the total number of ED admissions above 22.4 degrees C was observed during the summer periods between 2000 and 2005 in Murcia, Spain [19] and in Adelaide [15]. However, by giving equal weighting to all conditions, this approach is also likely to hide a number of condition-specific threshold effects.

The risks of extreme heat on morbidity are particularly important in a country such as Australia, given its hot climate and the likely increase in morbidity due to global warming [20]. The aim of this project was to assess the effects of extreme heat on the rate of ED admissions with extreme heat classified according to heatwave versus non-heatwave periods, and also according to maximum daily temperatures. In addition, maximum daily temperature was also used to help identify any temperature-morbidity thresholds for specific conditions.

METHODS

Location and Climate

The city of Adelaide in South Australia is the 5th largest city in Australia, with a population of 1.23 million in 2011. Adelaide is located at latitude $34^0$55m44s S, longitude $138^0$36m3s E, in Southern Central Australia. The average maximum daily temperature (degrees C) recorded for the period between 1977 and 2011 for November to March were November 25.2, December 27.0, January 29.3, February 29.4 and March 26.4.

Definition of a Heatwave Period

There is no universal definition of a heatwave although in a general sense it can be defined as a prolonged period of excessive heat. The Bureau of Meteorology defines a heatwave for Adelaide as either 5 consecutive days where the dry bulb temperature is 35 °C or greater; or 3 consecutive days where the dry bulb temperature is 40 °C or greater [14].

Data Collection Period and Sources

Data was collected for 3 weeks before and 3 weeks after 5 separate heatwaves that occurred between 2007 and 2009. The 5 heatwave periods that occurred during this period occurred on the following dates; 15/02/2007-19/02/2007, 28/12/2007 to 01/01/2008, 03/03/2008 to 17/03/2008, 26/01/2009 to 07/02/2009 (in which 3rd February was included although the maximum temperature reached only 33 °C), and 08/11/2009 to 15/11/2009. Discharge diagnosis codes were obtained directly from the ED administration offices of the 4 major public hospitals in Adelaide in the form of either an Excel (Microsoft) or Access (Microsoft) spread sheet. Climatic data for the study period were obtained from the Australian Bureau of Meteorology. All temperatures are reported in units of degrees Celsius (°C) throughout the manuscript.

Diagnoses of Interest and ICD-Codes

Primary discharge diagnoses were classified according to either the International Classification of Diseases, 10th revision (WHO 2007), or the ICD-9 classification system. We examined conditions that are known to be heat sensitive using the following international classifications of diseases (ICD, revisions 9 and 10): Cardiovascular disease (CVD) (ICD-9, 390-459; ICD-10, I00-99), Ischaemic heart disease (IHD) (ICD-9, 410-414; ICD-10, I20-I25), cerebrovascular disease (ICD-9, 430–438; ICD-10 I60-I69), composite CVD (CVD plus IHD plus cerebrovascular), respiratory (ICD-9, 460-519; ICD-10, J00-J99), asthma (ICD-9, 493; ICD-10 J45-J46), mental health related (ICD-9, 290-299; ICD-10, F00-F99), renal (ICD-9, 580-599; ICD-10 N00-N39), foodborne (ICD-9, 30–39, 50-59; ICD-10, A02-A49) and heat-related conditions (ICD-9, 276.5, 992,E900; ICD-10, E86, T67,X30). We excluded admissions for those aged less than 15 years old.

Statistical Analysis

All analysis was performed using STATA® version 13.1 (StataCorp®,Texas, USA) with Microsoft Windows 7®. To investigate the association between heat and ED admissions, for each analysis we used a case-crossover design, an appropriate method to use with case-only data, particularly when the outcome is acute and the exposure is brief and transient [21]. A total of 5 heatwaves were used in the analysis which lasted for 5, 5, 15, 13 and 8 days respectively. For each individual heatwave, we matched control days to case days using the day of the week. A period of 3 weeks prior to the first day of each heatwave and 3 weeks after the last heatwave day was used as the control period for each heatwave. In this way we accounted for any potential effects of year, month and day of week. If possible, each case day was matched with a non-heatwave day that was 7, 14 and 21 days before that heatwave day and 7, 14 and 21 days after that heatwave day. For heatwaves that lasted longer than 1 week, only the matching days that were also non heatwave days were used for control days. Each case day was therefore matched to a maximum of 6 control days (3 days prior to and 3 days after each heatwave). In total there were 244 control days compared with the 46 case days (an average of 5.3 control days to each case day). The greater number of control days was used to help increase statistical power. Analysis of the effects of heatwave was performed using conditional logistic regression with the day type (heatwave, non-heatwave) used as the dependent variable and the number of ED admissions for each day as the independent variable. In sensitivity analysis we assessed the potential for a delayed effect of the heatwave by using the number of admissions on the following day (i.e. a one day lag) for the independent variable. A grouping variable was used to indicate the relevant group of days for each case day which consisted of the case day and its matched control days. Analysis was stratified according to 3 age groups that are commonly employed in morbidity studies; 15 to 64 years of age (adults), 65 to 74 years of age (adult retirees), and 75 years or older (older people) [3].

To assess the effects of the maximum daily temperature on the average number of ED admissions, using the same data for the 5 heatwave periods and for the control periods either side of the heatwave, the number of ED admissions per day was aggregated for each condition of interest into categories of <25 °C, 25-29 °C, 30-34 °C, 35-39 °C, and 40+ °C. Five degree Celsius intervals were used as an objective approach to first establishing broad temperature range effects on admissions. Only the 3 weeks either side of the heatwaves was used as control periods since including additional data from between the heatwaves may have introduced a seasonal bias. Analysis was performed using negative binomial regression with robust standard errors to account for the autocorrelation in ED admissions across the average daily temperatures. The dependent variable was the number of ED admissions and the only independent variable was the categorical variable for temperature. To identify any critical threshold temperatures at which changes in condition-specific ED admission rates occurred, the nl command was used for non-linear regression in STATA®, fitting splines to the data with the critical temperature cut-points used as the knots. Approximate starting values for possible critical threshold values were based on an assessment of a scatterplot of the average number of admissions against maximum daily temperature. One degree Celsius intervals were used for this analysis as this was considered to be sufficiently precise in terms of critical thresholds, and in addition there were generally a sufficient number admissions for each condition at this level of precision. The exact values of the cut-points were then identified using the nl command. The mean number of admissions for each degree of temperature was used as the dependent variable and the degree of temperature (°C) as the independent variable.

RESULTS

ED Admissions and Heatwave Periods

Table **1** shows the total and age-stratified number of ED admissions, the total number of case and control days analysed, and the heatwave effects for each condition of interest. There was a more than 3-fold increase in the odds of an ED admission for a heat related condition amongst adults overall ($p<0.001$) and between a 2 and 6-fold increase for each of the 3 individual age groups ($p<0.001$ for each). The odds of renal-related ED admissions increased by 13% overall ($p<0.001$) during heatwave periods and by 12% ($p=0.04$) and 14% ($p=0.05$) in the 15-64 and 75+ year old age groups respectively with a similar although non-significant 15% increase in the 65-74 year old age group. There was a 22% increased odds of admission for IHD in the 15-64 year old age group ($p=0.01$) but no increase in the other age groups or overall. The odds of ED admission for respiratory and mental health conditions increased by 19% and 34% respectively in the 65-74 year old age group but not in the other age groups. There were no heatwave related effects for any of the other specific conditions of interest. All effects were substantively similar when the admissions during the one day lag were used (Table **1**), except for an increase for total IHD admissions (OR=1.12, 95% CI=1.01, 1.24), a lack of effect for respiratory conditions in the 65-74 year old age group (OR=1.12, 95% CI=0.96-1.31), a lack of effect for mental health conditions in the 65 to 74 year old age group (OR=1.27, 95% CI=0.97-1.68), and a significant increase for foodborne conditions in the 15 to 64 year old age group (OR=2.47, 95% CI=1.10, 5.53)

ED Admissions and Maximum Daily Temperature

Table **2** shows the effect of the maximum daily temperature on ED admission rates for 25-29 °C, 30-34 °C, 35-40 °C and above 40 °C compared to temperatures of less than 25 °C. Significant

Table 1: Age-Stratified Effects of Heatwave Versus Non-Heatwave Periods on Emergency Department Admissions in Adelaide 2007 to 2009

	Case days		Control days		Same day	One day lagged
	Admissions [n]	Days [n]	Admissions [n]	Days [n]	admissions OR [95% CI][1]	admissions OR [95% CI][1]
Cardiovascular Disease						
Aged 15-64	586	46	3145	244	0.99 [0.91, 1.08]	0.99 [0.91, 1.08]
Aged 65-74	283	46	1616	244	0.92 [0.81, 1.05]	0.97 [0.85, 1.10]
Aged 75+	631	46	3435	244	0.97 [0.90, 1.05]	0.98 [0.91, 1.06]
Total	1500	46	8196	244	0.98 [0.90, 1.05]	0.98 [0.93, 1.04]
Ischaemic heart disease						
Aged 15-64	196	46	849	244	**1.22 [1.04, 1.43]**	**1.21 [1.04, 1.41]**
Aged 65-74	96	46	495	244	1.02 [0.82, 1.28]	1.11 [0.89, 1.38]
Aged 75+	152	46	839	244	0.95 [0.79, 1.14]	1.01 [0.84, 1.22]
Total	444	46	2183	244	1.08 [0.97, 1.20]	**1.12 [1.01, 1.24]**
Cerebrovascular						
Aged 15-64	73	46	410	244	0.94 [0.75, 1.19]	0.96 [0.76, 1.21]
Aged 65-74	40	46	243	244	0.85 [0.59, 1.22]	0.84 [0.59, 1.19]
Aged 75+	120	46	592	244	1.06 [0.89, 1.28]	1.01 [0.84, 1.23]
Total	233	46	1245	244	0.99 [0.86, 1.13]	0.96 [0.84, 1.10]
Cardiovascular [composite]						
Aged 15-64	855	46	4404	244	1.02 [0.96, 1.07]	1.02 [0.97, 1.07]
Aged 65-74	419	46	2354	244	0.96 [0.89, 1.04]	0.99 [0.91, 1.07]
Aged 75+	903	46	4866	244	0.99 [0.94, 1.04]	0.99 [0.94, 1.04]
Total	2177	46	11624	244	0.99 [0.96, 1.03]	0.99 [0.96, 1.03]
Respiratory						
Aged 15-64	641	46	3400	244	1.00 [0.93, 1.08]	1.01 [0.94, 1.09]
Aged 65-74	198	46	882	244	**1.19 [1.01, 1.39]**	1.12 [0.96, 1.31]
Aged 75+	336	46	1729	244	1.03 [0.92, 1.15]	0.98 [0.87, 1.10]
Total	1175	46	6011	244	1.03 [0.98, 1.09]	1.01 [0.96, 1.07]
Asthma						
Aged 15-64	148	46	790	244	0.99 [0.84, 1.18]	1.01 [0.85, 1.20]
Aged 65-74	14	46	61	244	1.26 [0.70, 2.27]	1.36 [0.76, 2.41]
Aged 75+	10	46	43	244	1.26 [0.62, 2.56]	0.82 [0.35, 1.89]
Total	172	46	894	244	1.02 [0.87, 1.20]	1.02 [0.87, 1.20]
Mental health						
Aged 15-64	1078	46	5645	244	1.01 [0.96, 1.08]	1.01 [0.96, 1.08]
Aged 65-74	70	46	284	244	**1.34 [1.02, 1.78]**	1.27 [0.97, 1.68]
Aged 75+	86	46	368	244	1.23 [0.98, 1.57]	1.13 [0.89, 1.42]
Total	1234	46	6297	244	1.04 [0.98, 1.10]	1.03 [0.98, 1.09]
Renal						
Aged 15-64	542	46	2581	244	**1.12 [1.01, 1.23]**	**1.16 [1.05, 1.28]**
Aged 65-74	120	46	539	244	1.15 [0.95, 1.38]	1.18 [0.99, 1.42]
Aged 75+	258	46	1183	244	**1.14 [1.00, 1.30]**	**1.14 [1.00, 1.31]**
Total	920	46	4303	244	**1.13 [1.05, 1.21]**	**1.16 [1.08, 1.24]**
Food borne						
Aged 15-64	8	46	20	244	2.26 [0.97, 5.23]	**2.47 [1.10, 5.53]**
Aged 65-74	0	46	4	244	Not estimable	Not estimable
Aged 75+	0	46	2	244	Not estimable	Not estimable
Total	8	46	2	244	1.72 [0.78, 3.79]	1.89 [0.89, 4.02]
Heat related conditions						
Aged 15-64	185	46	165	244	**5.81 [2.88, 11.72]**	**5.04 [2.76, 9.20]**
Aged 65-74	50	46	57	244	**3.13 [1.96, 4.99]**	**3.57 [2.18, 5.85]**
Aged 75+	184	46	165	244	**2.50 [1.81, 3.46]**	**2.79 [1.96, 3.96]**
Total	419	46	387	244	**3.20 [2.50, 4.11]**	**3.48 [2.68, 4.52]**

[1]Effects estimated using conditional logistic regression. Heatwave days were matched by day of the week to control days up to 3 weeks prior to each heatwave and up to 3 weeks post heatwave. OR=Odds Ratio. 95% CI=95% Confidence Interval.

Table 2: Effects of Maximum Daily Temperature on Emergency Department Admissions in Adelaide 2007-2009 for 25-29 ^{0}C, 30-35 ^{0}C, 35-40 ^{0}C and >40 ^{0}C Compared to 25 ^{0}C[1]

	< 25 °C [Referent group]	25-29 °C IRR [95% CI]	30-34 °C IRR [95% CI]	35-40 °C IRR [95% CI]	> 40 °C IRR [95% CI]
CVD	1.00	0.96 [0.89, 1.02]	0.97 [0.89, 1.05]	0.97 [0.91, 1.05]	**0.88 [0.79, 0.97]**
IHD	1.00	0.98 [0.88, 1.10]	1.01 [0.89, 1.13]	0.99 [0.88, 1.13]	0.98 [0.84, 1.14]
Cerebrovascular	1.00	0.88 [0.75, 1.04]	1.03 [0.86, 1.23]	1.00 [0.84, 1.19]	0.86 [0.67, 1.09]
Cardiovascular [composite]	1.00	0.95 [0.89, 1.02]	0.98 [0.91, 1.07]	0.98 [0.91, 1.06]	**0.89 [0.80, 0.99]**
Respiratory	1.00	0.96 [0.87, 1.05]	0.99 [0.89, 1.10]	1.01 [0.91, 1.13]	0.98 [0.87, 1.10]
Asthma	1.00	0.88 [0.73, 1.05]	**0.77 [0.63, 0.95]**	1.03 [0.85, 1.24]	0.95 [0.75, 1.22]
Mental health	1.00	1.03 [0.95, 1.11]	**1.11 [1.02, 1.20]**	**1.13 [1.05, 1.23]**	**1.11 [1.02, 1.21]**
Renal	1.00	0.96 [0.88, 1.05]	1.03 [0.94, 1.12]	1.03 [0.94, 1.13]	1.14 [0.99, 1.33]
Food borne	1.00	0.86 [0.32, 2.29]	1.15 [0.46, 2.86]	1.25 [0.51, 3.10]	1.50 [0.41, 5.42]
Heat related conditions	1.00	1.20 [0.86, 1.70]	1.29 [0.88, 1.89]	**3.37 [2.42, 4.70]**	**8.49 [5.35, 13.49]**

[1]Using a negative binomial regression model with robust standard errors. IRR=Incidence rate ratio. 95% CI=95% Confidence interval. CVD=cardiovascular disease; IHD=ischaemic heart disease. Cardiovascular [composite]=CVD + IHD + Cerebrovascular.

temperature effects were apparent above 35 °C for heat related conditions and above 30 °C for mental health related condition. Specifically, ED admissions for heat related conditions were 3.4 times higher at 35-39 °C ($p<0.001$) and 8.5 times higher at >40 °C ($p<0.001$), while ED admissions for renal conditions were non-significantly higher by 14% above 40 °C ($p=0.07$). Compared to temperatures of less than 25 °C, there was an 11% ($p=0.01$), 13% ($p=0.002$) and 11% ($p=0.01$) increase in admission rates for those diagnosed with a mental health at 30-34 °C, 35-39 °C and 40± °C respectively. Admissions for CVD declined by 12% above 40 °C ($p=0.01$) and admissions for asthma declined by 23% at 30-34 °C ($p=0.01$).

Critical Maximum Daily Temperatures

Figures **1A-1I** show the critical temperatures estimated from non-linear regression analysis of the ED diagnosis rates for each of the specific conditions studied. Cardiovascular disease conditions declined non-significantly above 39 °C, whereas ischaemic HD conditions and cerebrovascular conditions remained fairly steady throughout the temperature range. The composite measure of CVD which included CVD, IHD and cerebrovascular conditions also declined non-significantly ($p=0.11$) at 39 °C. There were significant changes in the temperature-ED admission rate trends for respiratory conditions at 22.3 and 40 degrees °C ($p<0.001$ for each) with decreasing admission rates between 18 and 22.3 degrees °C, increasing admission rates between 22.3 and 40 °C, and then decreasing admission rates above 40 °C. Admissions for asthmatic conditions were lowest at around 31 °C but trended higher with either lower or higher temperatures. Renal and heat related conditions rose sharply above approximately 39.5 and 37.6 °C respectively ($p<0.001$ for each). Although diagnosis rates for mental health related conditions mostly rose steadily with increasing temperature, there was a significant fall in rates above 39.0 °C ($p=0.008$) although this effect relied on a sharp drop from only 2 data points at 44 and 45 degrees. Foodborne conditions rose non-significantly at above 22.0 °C ($p=0.12$)

DISCUSSION

This study assessed the effects of heat on ED admissions for a range of different diagnostic conditions in the South Australian population over a 3 year period between 2007 and 2009. Increased heat exposure was defined in terms of both whether or not a heatwave was present and in terms of the maximum daily temperature. The use of maximum daily temperature was a more sensitive approach to examining heat effects than that of a heatwave versus non-heatwave period approach, which obscured the falls in ED admission rates at higher temperatures for mental health, cardiovascular and respiratory conditions. Plots of the daily maximum temperatures with ED admissions and non-linear regression analysis also demonstrated the very gradual and steady increase in ED admissions with increasing heat for some conditions compared to much sharper increases at temperature thresholds of 37.6 and 39.2 degrees for heat related and renal conditions respectively.

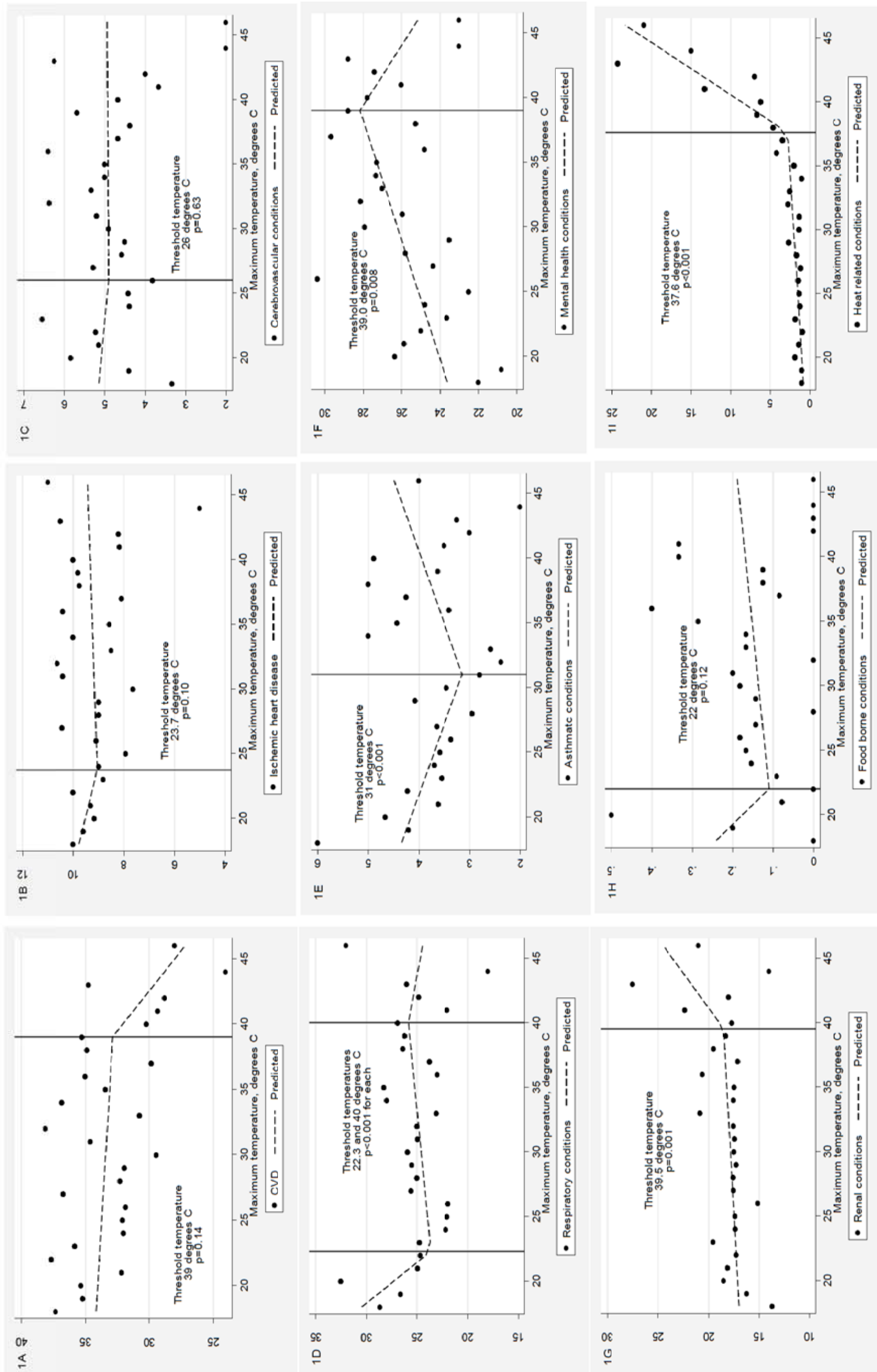

Figure 1: A-I: Mean number of emergency department (ED) admissions according to maximum daily temperature to the nearest ^{0}C.

A comparison between a case-crossover analysis approach where the heatwaves are the defined periods of interest, and a time-series approach using maximum daily temperatures was performed when examining temperatures, mortality and ED admissions in Brisbane between January 1996 and December 2005 [16]. Although essentially similar conclusions were drawn from the two different approaches, the patterns of the condition-specific admission rates with temperature were not assessed. A similar use of a case-crossover approach for heatwave period analysis and use of maximum daily temperatures within 5 degree categories also led to different conclusions as to the effects of heat when age groups were combined.

The finding of an absence of any increase in ED presentations with increased heat for mental health related conditions when assessed using defined heatwave periods (except for 15-64 year olds) agrees with a recent analysis of similar data for the 2008 and 2009 heatwaves in Adelaide [22]. The contrast between these findings, and that of previously identified effects of heat on mental health [23], might partly be explained by the sharp fall in mental health related ED admissions that was observed beyond a temperature of 39.5 degrees in this study. In addition, significant increases in ED admissions for mental health were observed at all temperatures above 30 degrees compared to 20 to 25 degrees. Therefore, using the heatwave defined period only i.e. when temperatures reach 35 degrees for 5 consecutive days, the effect of increased temperature on mental health admissions was diluted. Since we only had sufficient data to examine temperature-specific effects for the broadly grouped mental health related conditions, it is also possible that heat related effects which exist for specific mental health conditions and/or specific age groups were obscured [23].

There was a sharp increase in ED admissions for heat related conditions at 37.6 degrees. This effect was apparent with temperature classified at 5-degree intervals and particularly when using non-linear regression and 1-degreee intervals. The apparent sharp increase in heat related admissions at 37.6 degrees is in contrast to the finding of an approximately linear increase with daily maximum 3-hr temperature in heatstroke related ambulance dispatches in Japan [24], once temperatures rose beyond much lower thresholds of between 30 and 35 degrees depending on the Japanese city being examined [24] . An approximately linear increase in ambulance call-outs for heat-related illness with increasing daily temperature was also reported in Toronto, Canada across the whole of the summer period for 2005 [9]. However, threshold temperature effects were not explored and no descriptive data on the actual temperature ranges for the defined period were provided. A much lower threshold maximum daily temperature of 27.2 degrees was observed for increases in mortality in Montreal, Canada [25]. The disparity in these findings might relate to other climactic and environmental conditions including the degree of humidity and pollution [26, 27, 28] which are specific for each city.

The finding of a 22% increase in ED presentations for IHD conditions during heatwave periods amongst 15-64 year olds broadly agrees with an earlier analysis of the 2008 and 2009 heatwaves in Adelaide that used the same ICD classification codes and observed a 39% increase in admissions during the more intense 2009 heatwave also in those aged 15-64, but not amongst older individuals or during the 2008 heatwave [22]. Our temperature specific analysis showed no major changes in IHD ED admissions across the temperature range studied over all age groups combined suggesting that the difference in effects observed during the 2008 and 2009 heatwaves in Adelaide were perhaps not a result of the more intense temperatures that occurred in 2009 [22]. Similar to our findings for mental health, we also observed a sudden decrease in CVD-related ED admissions at much higher temperatures of around 39 degrees C, but a very steady increased admission rate below that cut-point. This temperature relationship is different to the U-shaped relationship between heat and CVD-related mortality reported in the UK [17] where temperatures are much colder than Australia in the winter but also less severe in the summer. The heat-ED admission relationship for CVD admissions in Adelaide was also different to that seen in Brisbane [29] where sudden increases in CVD ED visits occurred at around 32 degrees C with no drop in risk at higher temperatures, although temperatures above 39 degrees C were not studied. As with heat related conditions, the differences in findings between the 2 Australian capital cities may relate to the differences in humidity between the 2 climates as well as the exacerbation of temperature effects in Brisbane from increases in PM_{10} levels [29]. The generally steady ED admission rate with increased temperature observed for IHD is similar to findings for ischaemic stroke in Brisbane, although in that study there was a suggestive decline in ischaemic stroke admissions between maximum temperatures of 21 and 36 degrees and then an increase between 36 and 41 degrees [27].

Renal related ED admissions were significantly increased during heatwaves, particularly amongst the elderly, as observed before in both Adelaide [22] and Brisbane [30], and the additional finding in this study of a sharp increase in renal admissions above 39.3 degrees is in line with the finding of far higher admission rates for renal disease in the more intense 2009 heatwave than in the less extreme 2008 and previous heatwaves in Adelaide [22]. In a gender specific analysis of hospital admissions for renal disease that studied heatwaves in Adelaide between 1995 and 2006, there was a significant increase in hospital admissions of 13% and 19.6% for 15-64 and 85+ year olds respectively, which was also more apparent amongst females [31]. This was as a result of increased admissions for renal disease [10%], renal disease with acute effects of heat (11-fold), and acute renal failure [25.5%] rather than admissions for dialysis which were not increased [31]. In an analysis of hospital admissions for 8 different renal conditions in New York State between 1991 and 2004, there was an increase in acute renal disease, and urinary tract infections on days of increased heat, whereas admissions for renal calculi peaked 2 to 3 days after temperatures increased [32]. Results were similar when the authors excluded temperatures above the 90^{th} percentile, suggesting that the associations were not driven by extreme temperatures but rather by a steady increase with temperature.

Although our data included only summer months, we observed an apparent increased risk of asthma related ED admissions during cooler days. An increased risk for a respiratory event with decreased temperatures has been observed with a number of different conditions although these have usually been in relation to minimum temperatures rather than maximum temperatures. The risk of Sudden Infant Death Syndrome [SIDS] is linearly and negatively associated with mean minimum and maximum daily temperatures [33, 34] and colder weather is also associated with increased risk of asthma [35]. Increased ED admissions for asthma during Winter periods have been associated with temperature inversions of hot and cold air which lead to increased concentrations of air pollutants becoming trapped in the colder air [36], and respiratory deaths are also increased with lower temperatures, particularly when air pollution is also higher [37].

Although a recent study in Australia found a significant increase in ED admissions and mortality for a variety of diagnostic conditions, the effects of heat likely differ across States which have wide variation in humidity levels.. Optimal humidity in terms of lowest mortality was defined as between 24% (for respiratory diseases) and 51% (for digestive system diseases) in a time-series analysis of deaths in Castillion, Spain between 1980 and 1998 [38]. In the UK, where humidity is higher and air conditioning much less widespread, a heatwave is defined as soon as the critical threshold temperature for a particular region is reached on any given day [5], typically around 30 degrees C. This shows the importance of not only assessing increased mortality and morbidity risks by using daily maximum temperatures rather than by prolonged periods, but also the need to estimate location specific thresholds. In Europe, the rate of respiratory related admissions is strongly influenced by location [39].

LIMITATIONS

Due to the relatively low number of admissions within each age category for most conditions we were unable to perform a temperature-specific approach according to age groups, for which a larger dataset over a more extended time period would be required. Similarly we had only sufficient data to assess broad morbidity groupings and therefore heat-ED admission relationships for specific conditions within ICD groups may exist but have been either diluted or missed entirely. We did not adjust for levels of particulate matter which are known to affect morbidity, particularly in hot conditions [29] or ozone levels that also increase risk of mortality and interact with temperature [40]. The analysis of our data was based upon a strategy of fitting linear effects to the observed data in order to identify cut-points. Other researchers have used smoothed spline and lowess curve approaches [12, 29] which track the relationships more closely but by their smoothed nature do also not identify specific thresholds.

CONCLUSION

Although heatwave effects on ED admissions were mostly small for each of the conditions, analysis by maximum daily temperature revealed a number of further associations as well as interesting underlying patterns in the data. Effects of temperature on ED admissions and in particular the effects of higher temperature on mental health related conditions may be masked when admission rates are assessed by the less sensitive temperature classification of a heatwave period. This study has shown that critical temperature threshold effects exist for certain morbidities. This provides public health policy makers with important additional information when considering the optimal information advice strategies to reduce risks. Similarly, researchers should consider assessing the health effects of heat using daily temperature data rather than heatwave periods which vary in definition and may not adequately capture the true temperature-health event relationships which are also likely location specific. It is important to note that there will also be differences in temperature thresholds between cities, countries and global regions. The importance of heat related morbidities and ED presentations cannot be underrated since some are potentially fatal especially amongst the older and frailer population. In summary, our findings suggest that health care professionals assisting persons at greater risk such as older people and those with known heat-affected conditions should be made aware of the critical maximum daily temperatures for their locations beyond which the risk of serious health events increases sharply.

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