Short-term effect of heat waves on hospital admissions in Madrid: Analysis by gender and comparision with previous findings

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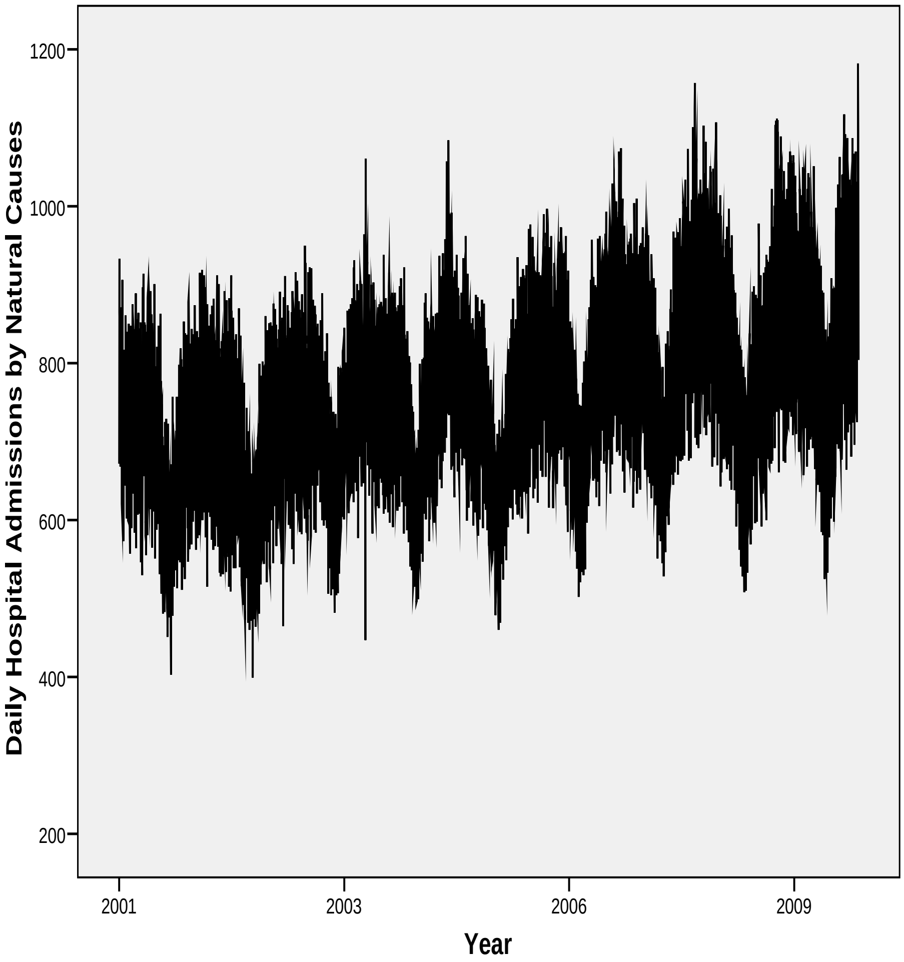
Daily Hospital Admissions by Natural Causes
1200
1000
800
600
400
200
2001
2003
2006
2009
Year

SHORT-TERM EFFECT OF HEAT WAVES ON HOSPITAL ADMISSIONS IN MADRID: ANALYSIS BY GENDER AND COMPARISION WITH PREVIOUS FINDINGS.

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Introduction

Global warming affects health through multiple exposures and pathways, in and is turn deeply influenced by climate change. Every year, several million deaths are caused by environmental factors, many of which are aggravated by climate change or its drivers (WHO, 2016). The adverse effects of climate change on health are varied, complex and far-reaching. Essentially, climate change acts as a multiplier for global health threats, compounding many of the health issues communities already face. Disproportionately affect the health of vulnerable groups and people in lower income countries, thus exacerbating inequalities and gender differences (Watts et al., 2018).

One of the mechanisms for adapting to climate change is the implementation of prevention plans. The main aim of such plans is to minimise the impact which high temperatures have on population morbidity and mortality (Boeckmann and Rohn 2014; Åström et al., 2014). Although evidence of their effectiveness, as well as that of other population-adaptation measures (Bobb et al., 2014) and improvements to healthcare (Ha and Kim., 2013) and infrastructures (Vandentorren et al., 2006), is found in a clear reduction in the impact of heat on mortality (Díaz et al., 2015a; Schifano et al., 2012; Mirón et al 2015; Díaz et al., 2018), it is nonetheless true to say that these plans refer to the *general* population. While some of them pinpoint especially vulnerable groups (MSSSI, 2017), no account is taken of the possibility that there may be differences in effectiveness according to sex, age and socio-economic status (Benmarhnia et al., 2016). Similarly, no consideration is given to the fact that even the temperatures for activating such plans may vary according to age, gender (Na et al., 2013) and region (Carmona et al., 2017; Na et al., 2013).

When used in a health context, the term "sex" refers to the biological and physiological characteristics that define men and women, whereas "gender" refers to the social concepts of the functions, behaviour, activities and attributes which each society considers appropriate for men and women (WHO, 2012). It is evident that from the standpoint of the effects of heat, both “sex” and “gender” must be borne in mind. In addition to differences of a collective nature, such as body size, physical condition and state of acclimatisation to heat (Gagnon and Kenny 2012), there are social factors such as differences in social isolation, something that tends to be greater among men than among women, and may prove a risk factor in a heat-wave situation (Canouï-Poitrine et al., 2006). However, there are also factors of a physiological nature, such as women’s tendency to sweat less than men (Gagnon and Kenny 2012), a natural thermoregulation mechanism which might explain the greater impact of heat on women than on men.

Some studies have shown differences in mortality impacts between men and women. In terms of numbers of heatwave deaths, these are greater in women than in men, given the higher number of women in all age groups (WHO, 2015). In some cases, the effects on gender are age-specific. In certain countries in Europe, for example, the effects are greater on women in the elderly age groups (D’Ippoliti et al., 2010). In short, the role of gender as a risk factor remains unclear and has only been assessed for a limited number of developed-country situations. In some countries, where the division of labour is strong with men or women undertaking strenuous tasks in outdoor or indoor heat or where cultural factors as expressed through dress lead to higher personal heat loads, there may well be clear gender effects.

Most studies which analyse the impact of heat on men and women separately, focus on mortality attributable to heat and conclude that it is women over the age of 65 years who are most affected by heat (Díaz et al 2002; Rey et al., 2007; Borrell et al 2006; D’Ippoliti et al., 2010; Bogdanovic et al 2013; Díaz et al 2015a), especially in the case of cardiovascular diseases (Díaz et al., 2002; Tian et al.,2013), though these differences are also observable, albeit to a lesser degree, in respiratory diseases (Monteiro et al 2013).

Studies that analyse the impact of heat waves on hospital admissions are less numerous than those that focus on mortality, and generally report less impact on admissions than on mortality (Kovats et al., 2004; Mastrangelo et al.,2006; Linares and Díaz 2008; Li et al 2015). Moreover, there are even fewer studies which analyse this impact on morbidity by gender (Na et al., 2013; Ha et al., 2014; Monteiro et al., 2013).

As regards the time trend in the impact of heat on morbidity and mortality, there are likewise few studies, and all of these focus on the variations seen in mortality (Díaz et al 2015; Konkel, 2014, Schifano et al., 2012; Mirón et al., 2015; Ha and Kim, 2013; Díaz et al., 2018). Moreover, knowing the temporal evolution of heat impact over hospital admissions allows us to check whether, as with mortality, there is a decreasing trend and thus have another health indicator that shows the adaptation of the population to heat (Díaz et al., 2018; Vicedo-Cabrera et al., 2018).

Accordingly, our study's twin objectives were to analyse: on the one hand, whether there was a different pattern between men and women in terms of the impact of heat on different specific causes of hospital admissions in Madrid; and on the other, whether this impact might have changed with respect to that detected by previous analyses (Linares & Díaz, 2008) performed in the same setting.

2. Material and methods

2.1. Data

2.1.1 Dependent variable

The dependent variable was the number of daily emergency hospital admissions due to natural (International Classification of Diseases-10th Revision (ICD-10): A00-R99), respiratory (ICD-10: J00-J99) and circulatory causes (ICD-10: I00-I99) in the Madrid Autonomous Region, across the period 1 January 2001 to 31 December 2009. We stratified our analysis by sex, on the basis of pooled, anonymised data supplied by the National Statistics Institute (*Instituto Nacional de Estadística/INE*).

2.1.2 Independent variable

The independent variable was maximum daily temperature in degrees Celsius obtained at the Madrid-Retiro reference observatory during the study period. These data were furnished by the State Meteorology Agency (*Agencia Estatal de Meteorología/AEMET*).

2.1.3 Effects modifiers

Studies conducted in Madrid have shown an association between hospital admissions and variables of chemical acoustic and pollen . To control for their effect on emergency hospital admissions, we therefore included these in the analysis as control variables, which can be broken down as follows:

Chemical air pollution (Díaz et al., 2001),

The data used correspond to daily mean concentrations during the period 2001-2009, of:

- particles with an aerodynamic diameter of 10 micrometers (PM_{10}) or less, in µg/m^3
- particles with an aerodynamic diameter of 2.5 micrometers ($PM_{2.5}$) or less, in µg/m^3
- tropospheric ozone (O3) in µg/m^3

- nitrogen dioxide (NO_2) in µg/m^3

Acoustic pollution(Tobías et al., 2001; Recio et al. 2016)

- mean daily equivalent continuous sound levels (leqd), which included readings from 7:00 to 23:00 hours in dBA.

mean nocturnal equivalent continuous sound levels (leqn), which included readings from 23:00 to 7:00 hours in dBA.The data on chemical air pollution and acoustic pollution were both recorded by the Madrid Municipal Air Quality Monitoring Grid, made up of 26 remote automatic stations distributed over the territory and operated by the Madrid City Council. These stations are of 3 types, i.e., urban, traffic and suburban.

Pollens(Díaz et al., 2007)

The data used correspond to the daily mean pollen concentrations (grains/m^3), as recorded at the monitoring station which belongs to the Pharmacy Faculty at Madrid's Complutense University, and forms part of the Madrid Regional Health Authority Palynology Network (*Red Palinológica de la Consejería de Sanidad de la Comunidad de Madrid/PALINOCAM*). The pollens considered as control variables were:

- *Olea europaea (*olive) pollen (grains/m^3)
- *Cupresaceae* pollen (grains/m^3)
- *Platanaceae* pollen (grains/m^3)
- *Gramineae* pollen (grains/m^3)

Other control variables

This model controls both for seasonalities of 90 (three monthly) and 120 (four monthly) days, through the use of sine and cosine functions with these periodicities, and for the trend of the series and its possible autoregressive nature. The days of the week were also introduced as dichotomous variables.

2.2 Methodology of analysis

2.2.1 Determination of the threshold temperature and lagged variables

The study of the impact of heat was carried out for the summer period (June-September).

To determine the threshold temperature of hospital admissions during heat waves ($T_{threshold}$), we drew up a scatterplot diagram showing the prewhitened series of daily hospital admissions (Box et al., 1994) on the vertical axis and the maximum daily temperature on the horizontal axis, with the corresponding confidence intervals (Díaz et al 2015b; Carmona et al 2016; Sánchez-Martínez et al., 2018).

The $T_{threshold}$ value was associated with the percentile corresponding to the temperature in the time series of maximum daily temperatures for the summer months (June-September).

Based on the values of $T_{threshold}$, we calculated the variable T_{heat}, defined as follows (Díaz et al., 2006; Díaz et al., 2015b; Carmona et al., 2016; Sánchez-Martínez et al., 2018):

$T_{heat} = 0$ if $T_{max} < T_{threshold}$

$T_{heat} = T_{max} – T_{threshold}$ if $T_{max} > T_{threshold}$

Given that the effect of each heat wave on morbidity is not immediate, the following lag variables, regarding to temperature were calculated: T_{heat1} (lag 1), which takes into account the effect of the temperature on day “d” on mortality one day later “d+1”; T_{heat2} (lag 2), which takes into account the effect of the temperature on day “d” on morbidity two days later “d+2”; and so on successively. The numbers of lags were selected based on existing literature. Heat impacts occur at shorter time than cold impacts on health (Moghadamnia et al., 2017). Previous studies in Madrid (Alberdi et al., 1998; Díaz et al., 2002; Linares & Díaz, 2007) indicates that heat waves effect is until lag 4; for this reason the authors have introduced lags for T_{heat} at short-term effect, T_{heat}: lags 1-4.

In the case of chemical pollutants, pollens and acoustic pollution, we created variables regarding each air pollutant, each species of pollen and each indicator of acoustic pollution lagged until lag 4, again based on the existing literature (Díaz et al., 2001; Tobías et al., 2002; Díaz et al., 2007).

2.2.2 Generalised linear modelling with the Poisson link

In order to determine the corresponding relative risk attributable to heat values for each cause of admission and by sex, generalised linear model (GLM) methodology with the Poisson regression link were used first.

The procedure used to determine significant variables in the modelling process for the calculation of the RRs was «Backward-Stepwise», beginning with the model that included all the independent and control variables with their corresponding lags, and gradually eliminating those which individually displayed least statistical significance, with the process being reiterated until all the variables included were significant at $p<0.05$.

Increases in Relative Risks (RR) were calculated for increases in the following units of each independent variable:

T_{heat}, every 1^0C increase above the designated threshold temperature;

Chemical pollution, every 10 µg/m^3 increase in the respective pollutants;

Acoustic pollution, every increase of 1 dB(A)

Pollens, every 10 grain/m^3 increase in the respective pollen concentrations.

Based on these RRs, we calculated the Attributable Risk % (ARs) associated with the respective increases, via the equation (Coste & Spira, 1991): AR% = (RR-1/RR) *100.

We then assessed whether or not there was overdispersion in the model, since it can lead to an underestimate of the real variance and give rise to the possibility of consideration being given to certain coefficients, whether significant or non-significant. As there was overdispersion in all of our models, we chose to use a negative binomial regression model instead of Poisson regression throughout.

2.2.3 Calculation of attributable mortality

Given that the AR% represents the percentage increase in mortality for each degree that the maximum daily temperature exceeds the threshold temperature, by knowing the number of degrees per day that this threshold is exceeded on heat wave days, the associated percentage increase in these admissions can be calculated, and based on the number of admissions, one can then calculate by how much these admissions have increased (Díaz et al., 2015b; Carmona et al., 2016; Sánchez-Martínez et al., 2018).

To compare the findings showed in previous studies (Linares & Díaz, 2007) with the new ones, authors will consider two factors:

- Previous threshold temperature (Tthreshold) calculated.
- Percentages of emergency hospital admissions increment for each degree of maximum daily temperature surpass Tthreshold, corresponding to AR%.

All data analyses were performed using the SPSS Statistics 20 and STATA v 14 statistical software programmes.

3.Results

The descriptive statistics of hospital admissions in the Madrid Autonomous Region are shown in Table 1. Over the 9-year study period, there were 2,568,133 admissions, 40.9% of which corresponded to men and 59.1% to women. In the case of circulatory-cause admissions, there was a total of 412,515 admissions, with a greater proportion corresponding to men (52.5%) than to women (47.5%); and in the case of respiratory-cause admissions, there was a total of 415,477 admissions, 57.9% of which were men and 42.1% women.

The descriptive statistics of the independent variables (maximum and minimum daily temperature) and control variables are shown in Table 2. Figures 1, 2 represent the time-series plot of temperature and hospital admissions showing the variation of exposure and response outcome.

Figure 3 shows the scatterplot diagram used to determine the maximum daily temperature above which there was a significant increase in all-cause hospital admissions in the Madrid Autonomous Region. As will be observed, the anomalies of the prewhitened series begin to be statistically significant above a maximum daily temperature of 34ºC. This temperature corresponds to the 82nd percentile of the maximum daily temperature series for the summer months (June-September). In other words, on 18% of summer days there was a significant increase in hospital admissions. During the 9-year period analysed, this temperature of 34ººC was exceeded on 198 days.

The results of the modelling process, for both men and women, and for specific causes are shown in Table 3.

As can be seen from Table 3, in the case of natural-cause admissions for both sexes there was a statistically significant association between these and T_{heat} at lag 3. This association was solely attributable to women, since the analysis by sex showed that this was the only group to display an association at the same lag as that observed for both groups.

Table 4 shows the variables that proved significant in the modelling process and, as will be seen, heat showed no effect on hospital admissions due to circulatory causes, either in both groups or in men and women alone.

Lastly, Table 5 shows the associations between high temperatures and respiratory-cause admissions, from which it will be seen that high temperatures were solely associated with admissions in women at lag 3, with a 3.5% of AR% (IC95%:1.6 - 5.4), than that obtained when natural-cause admissions were analysed in both sexes: 0.6% of AR% (IC95%:0.1 - 1.0) and in women 0.8% of AR% (IC95%:0.3 - 1.3).

The heat-related admissions obtained on the basis of the ARs% in the above tables are shown in Table 6, from which it will be seen that practically all such heat-related admissions were attributable to women, with respiratory diseases accounting for 33% of causes of admission.

4. Discussion:

4.1 Similar threshold temperature to mortality and hospital admissions.

The study’s first result of relevance is the fact that the threshold temperature of hospital admissions in the Madrid Autonomous Region is established at 34ºC. This is the same value as that obtained when the impact of high temperatures on daily mortality is analysed (Díaz et al., 2015b), something that lends robustness to the results because, despite having used two different health indicators, e.g., admissions and mortality, obtained from different sources, the effect of temperature first becomes manifest at the same maximum daily temperature. This temperature also coincides with that used by the Spanish Ministry of Health (MSSSI, 2017) for activation of the Heat Wave Prevention Plan for the Madrid Autonomous Region. However, it should be borne in mind here that our study covered all hospitals in the Madrid Autonomous Region and that differentiation by isoclimatic area, as was done in the case of mortality (Carmona et al., 2017), would probably yield different admission temperatures for each of these areas, since the heat-wave definition temperature is affected by different local factors (Montero et al., 2012), including adaptation to a specific area's climatic (Curriero et al., 2002), demographic (Mirón et al.,2015), socio-economic (Vandentorren et al.,2006) and healthcare characteristics (Ha and Kim, 2013).

4.2 Time trend in the threshold temperature

In terms of time trend, this temperature went from 36.5ºC in the period 1995-2000 (Linares and Díaz, 2008) to 34ºC in the period analysed (2001-2009). Some studies indicate that the over-65 age group is especially susceptible to the effects of heat (Díaz et al 2015a; Linares and Díaz, 2008; Michelozzi et al., 2009; Lin et al; 2009), which means that the heat-wave definition temperature is affected by the percentage of the population aged over 65 years, in as much as the higher the percentage of the population over the age of 65, the lower the heat-wave definition temperature (Montero et al 2012). In our case the percentage of over-65-year-olds rose from 13.6% in the period 1995-2000 to close on 14.5% in 2001-2009 (INE 2017), something that could account for this drop in the hospital-admission threshold temperature. Yet, mention must also be made of other factors that would go in the opposite direction, in that an improvement in such factors would entail better acclimatisation to heat and, by extension, a rise in the heat-wave definition temperature. Among these would be improvements in infrastructures, such as access to air-conditioning, better living conditions and healthcare services (Fouillet et al., 2008; Gasparrini et al., 2015; Kyseli and Kriz, 2008), and even the existence of heat wave action plans which are proving effective in ameliorating the impacts of heat on the population (Tan et al., 2007; Schifano et al., 2012; Rey et al., 2007), and in particular in reducing mortality in the over-75 age group (Díaz et al., 2015a; Ruuhela et al., 2017; Bobb et al., 2014). Although we found no studies have analysed the time trend in heat threshold temperatures in terms of hospital admissions, studies conducted in Spain (Díaz et al., 2018) report somewhat inconclusive results in this regard, i.e., while threshold temperatures were observed to have fallen in some provinces, they were seen to have remained practically constant or to have risen in others. In the case of Madrid, this temperature remained constant at 36ºC across the periods 1983-1992 and 1993-2003, and then dropped to 34ºC during the period 2004-2013 (Díaz et al., 2018), a finding in line with the results obtained in this study for hospital admissions.

4.3 Evolution in Attributable Risks (AR%)

From a quantitative perspective, the impact of high temperatures on natural-cause hospital admissions in both sexes went from 4.6% in the period 1995-2000 to 0.6 % (95%CI: 0.1 – 1.0) in the 2001-2009 period. The AR% value of 0.6% is much lower than that encountered for heat-related mortality during this same period in Madrid (Díaz et al., 2015b): According to this early study, the AR% of mortality, with a similar heat-wave definition temperature, would be 6.7% (95%CI: 5.7–7.7), significantly higher than that for admissions. Heat’s lower impact on admissions than on mortality has already been reported by a number of studies (Linares and Díaz, 2008;, Kovats et al., 2004, Mastrangelo et al., 2006), and might well be explained by the fact that processes linked to heat-related mortality tend to be acute processes which develop within a very short space of time (Mastrangelo et al., 2006) and so result in the persons affected not being admitted to hospital. Ranking high among such causes would be circulatory diseases (Alberdi et al., 1998; Argaud et al 2007), since respiratory diseases usually present at a later point in time in the case of heat, as a consequence of the exacerbation of other already existing diseases (Viegi et al., 2006), something that is in line with the results found in this study in terms, not only of the diseases themselves, but also of the lags at which the association with heat appears. For these reasons, studies such as the one conducted in Apulia on the impact of the 2011 heat wave on cardiovascular diseases, using calls to the emergency and telemedicine services as an indicator (Brunetti et al, 2014), provide a new perspective for the study of the effect on morbidity in relation to cardiovascular diseases.

4.4. Impact of heatwaves by gender

There are few studies which analyse the relationship between high temperatures and hospital admissions with a gender focus. In some of these, differences by sex are indeed in evidence. Hence, in the city of Copenhagen a 9.5% increase was observed in the number of respiratory-cause admissions among women as opposed to men, (Wichmann et al, 2011), while another study conducted in South Korea highlighted the greater susceptibility of women when it came to heat-related hospital admissions (Son et al, 2014). Then again, other studies report no gender-related differences (Chan et al., 2013; Green et al., 2010), or even a higher risk among men (Tong et al., 2014; Phung et al., 2015; Bai et al., 2014).

From a physiological standpoint, under high-temperature conditions women display a lower heat-dissipation capacity, possibly due to the fact that they have a lower capacity for sweating than men do (Gagnon and Kenny, 2012), and are endowed with a thicker layer of subcutaneous fat, since adipose tissue is more insulating than other tissue, receives a relatively poor blood supply from the peripheral circulation, and acts as insulating layer in the event of vasoconstriction. Furthermore, sex hormones have an important influence on thermoregulatory mechanisms, i.e., oestrogens favour the dissipation of heat by central thermoregulatory mechanisms, which facilitate an efficient response in the form of cutaneous vasodilation and sweating at a local level (Guyton and Hall, 2011). Among women of advanced age, hormonal changes due to menopause have a direct impact on their thermoregulatory capability, making them more vulnerable to the effects of high temperatures.

In addition to the physiological factors underlying individuals' different heat-adaptation capacities, there are other determinants, such as the study population's above-described demographic and socio-economic characteristics and patterns of exposure. Thus, in the case of Korea, a greater susceptibility was attributed to women of advanced age with a low educational level (Son et al., 2014). Similarly, in the 2009 heat wave in southern Australia, elderly women were identified as an especially vulnerable population, in that they displayed a higher risk of suffering one or more symptoms during heat waves, and were more reticent when it came to asking for help (Nitschke et al., 2013). In our case, the demographic profile of the Madrid Autonomous Region showed that in 2009 women outnumbered men in the over-75 age group, i.e., 291,207 women versus 165,814 men (INE 2017). This finding could be regarded as an explanation which supports our results.

The number of heat-related hospital admissions, put at 1275 (95%CI: 276-2147) or 6.4 admissions (95%CI: 1.4-10.8) per heat wave day, shows that this is indeed a relevant problem in Madrid. Identification of respiratory causes as the only significant cause of admission, namely, that there might be no circulatory-cause admissions, is of great importance when it comes to hospital management. In this connection, it should be borne in mind that only 33% of recorded admissions are due to respiratory causes. There are other diseases, including neurodegenerative-type (Linares et al 2015) and renal diseases (Hansen et al., 2008), among others, which were not analysed in this study and are strongly influenced by the existence of heat waves, and whose symptoms become aggravated in episodes of extreme heat.

4.5 Public health concerns

From the point of view of implementing heat health warning systems, these findings showed have an impact on hospital management, since they allow us to know which emergency hospital admissions will be affected, at what time the event will occur and with what attendance. According to this and other studies (Davis and Novikoff, 2018) it will not be necessary to overstate the emergency services for circulatory causes, since these will not be affected by an increase in admissions from these causes, but admissions for respiratory causes.

4.6 Limitations and conclusion

A limitation to this study is that we had no explanatory variables, apart from individuals' age and home address. In particular, we were unable to control for factors such as individual socio-economic data, lifestyles (such as access to air-conditioning) and comorbidities, which may influence differences in mortality in people in different cities (Baumgart et al., 2005; Vodonos et al.,2015). These factors can also act as confounders or effect modifiers of the relationship between temperature and hospital admissions. Even so, control for much of this residual confusion was achieved by including variables in the model, such as the trend of the series, day of the week, seasonalities of 90 and 120 days, and the autoregressive nature of the series.

It should also be mentioned that as this was a longitudinal ecological study, the results cannot be extrapolated at an individual level. Whereas our study relied on exposure levels to a temperature determined on the basis of readings taken over a season as representative of the temperature of the entire province, there are studies which show that using values for smaller areas yields better results than does using values for the whole province (Carmona et al., 2017). Furthermore, data on air, pollinic and noise pollution refer to the average values recorded by monitoring stations in the city of Madrid, which may induce bias in the allocation of exposure (Samet et al., 2002).

Although the main factors of vulnerability by gender may vary geographically, depending on the social, economic and political setting, there are some commonalities across countries in terms of heat-risk factors, including being elderly, having pre-existing diseases (Davis and Novicoff., 2018), living alone, working outdoors or being involved in heavy labour indoors close to industrial heat sources. In some places, the nature of a person's dwelling where they are temporally or permanently resident (in a hospital or care home), being urban and poor and having certain medical conditions such as diabetes, fluid/electrolyte disorders and some neurological disorders, may also play a role. Moreover, vulnerability to heat waves increases being women and living in a single household (Wong et al., 2012). Some studies also points to a higher impact of heatwaves in people in conditions of social inequality, substance abusers, homeless and deprivation (Martin et al., 2016); outdoors seasonal workers due to their extensive physical exposure and occasionally with low salaries and unfavorable living conditions and individuals who perform heavily physical exercise. A special target group is pregnant women; heatwaves have been risk factor for adverse birth outcomes as low birth weight and premature birth (Arroyo et al., 2016; Ngo et al., 2016). The degree of adaptation to heat waves is probably explained, in large part, by six levels of adaptation interventions, including individual, interpersonal, community, institutional, environmental, and public policy levels (Wigth et al., 2016).

As has been noted throughout this paper, there are many factors, some of a local nature, that influence the effect of heat on hospital admissions, which is why these results cannot be extrapolated to other places. It is therefore necessary for studies of this type to be undertaken at a multicity level, at which they are practically non-existent. The impact of heat on mortality is known to be decreasing (Díaz et al., 2018), but it would be extremely useful, when it comes to prevention and resource-management policies, to have evidence that this is also happening at a hospital admission level. Furthermore, the heat pattern found, differentiated by different causes of admission and gender, underlines the need for these types of studies, with a view to the implementation of hospital heat-wave management measures.

Disclaimer

This paper reports independent results and research. The views expressed are those of the authors and not necessarily those of the Carlos III Institute of Health.

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Daily hospital admissions	*N*	*Min*	*Max*	*Mean*	*SD*
Natural causes	3287	399	1182	781.3	131.86
Natural causes: men	3287	139	519	319.9	61.88
Natural causes: women	3287	202	689	461.5	74.07
Circulatory causes	3287	51	213	125.5	27.84
Circulatory causes: men	3287	18	123	65.9	16.19
Circulatory causes: women	3287	19	110	59.5	14.44
Respiratory causes	3287	31	357	126.4	47.11
Respiratory causes: men	3287	18	190	73.2	25.59
Respiratory causes: women	3287	10	170	53.2	23.31

Table 1. Descriptive statistics of hospital admissions in the Madrid Region, by specific cause and gender across the period 2001-2009*.

***These figures are for all year.**

Variables	*N*	*Min*	*Max*	*Mean*	*SD*
Maximum temperature (ºC)	3287	1.0	38.6	20.2	8.8
Minimum temperature (ºC)	3287	-6.1	25.0	10.4	6.6
PM_{10} ($\mu g/m^3$)	3287	6.9	149.5	32.5	16.1
$PM_{2.5}$ ($\mu g/m^3$)*	2192	3.4	71.4	17.1	7.8
NO_2 ($\mu g/m^3$)	3287	17.6	142	59.4	17.9
O_3 ($\mu g/m^3$)	3287	3.7	89.4	35.7	18.1
Leqd (dB(A))	3287	59.4	69.0	64.6	1.4
Leqn (dB(A))	3287	55.0	67.2	59.4	1.4
Poaceae(grains/m^3)	3234	0	1873	19.4	93.0
Oleaceae (grains/m^3)	3234	0	480	3.3	20.5
Platanaceae (grains/m^3)	3234	0	3720	21.9	149.1
Gramineae (grains/m^3)	3234	0	458	7.3	26.9

Table 2. Descriptive statistics of the independent and control variables for Madrid across the period 2001-2009**.

*Data for the period 2003-2009.

**These figures are for all year.

	Variable(lag)	*RR*	*95%CI (RR)*	*AR (%)*	*95%CI (AR)*
Both groups	T_{heat} (lag 3)	1.006	1.001 - 1.010	0.6	0.13 - 1.01
	Leqd (lag 0)	1.040	1.034 - 1.046	3.9	3.27 - 4.44
	NO_2 (lag 0;2)	1.010	1.007 - 1.012	1.0	0.73 - 1.20
	Olea (lag 6)	1.001	1.000 - 1.002	0.1	0.01 - 0.23
Men	leqd(lag 0)	1.033	1.024 - 1.043	3.2	2.35 - 4.12
	NO_2(lag 2)	1.001	0.997 - 1.004	0.1	-0.27 - 0.42
	Poac(lag 4)	1.002	1.00 - 1.002	0.02	-0.14 - 0.19
Women	T_{heat}(lag 3)	1.008	1.003 - 1.013	0.8	0.27 - 1.31
	leqd(lag 0)	1.041	1.034 - 1.048	4.0	3.33 - 4.59
	NO_2(lag 0)	1.001	0.998 - 1.003	0.1	-0.20 - 0.31
	PM_{10}(lag 2)	1.001	0.998 - 1.003	0.1	-0.23 - 0.35

Table 3. Relative risk (RR) and Attributable Risk (AR%) of hospital admissions due to natural causes in the Madrid Region.

	Variable(lag)	*RR*	*95%CI (RR)*	*AR (%)*	*95%CI (AR)*
Totals	leqd(lag 0)	1.057	1.043 – 1.071	5.4	4.17 – 6.66
Men	leqd(lag 0)	1.081	1.064 – 1.099	7.5	5.98 – 9´01
	Olea(lag 12)	1.004	1.001 – 1.006	0.4	0.09 – 0.64
Women	leqd(lag 0)	1.050	1.031 – 1.069	4.7	2.97 – 6.44

Table 4. Relative risk (RR) and Attributable Risk (AR%) of hospital admissions due to circulatory causes in the Madrid Region.

	Variable(lag)	RR	95%CI (RR)	AR (%)	95%CI (AR)
Total	Leqd(lag 0;4)	1.054	1.033 - 1.075	5.1	3.24 – 7.01
	Leqn(lag 1)	1.036	1.024 – 1.049	3.5	2.33 – 4.69
	PM$_{10}$(lag 1)	1.016	1.010 – 1.023	0.5	0.18 – 0.79
	Poac(lag 4)	1.005	1.002 – 1.008	0.5	0.18 – 0.79
Men	Leqd(lag 0;4)	1.077	1.064 – 1.089	7.1	6.04 – 8.21
	NO2(lag 2)	1.015	1.008 – 1.023	1.5	0.77 – 2.23
	O3(lag 4)	1.040	1.013 – 1.066	3.8	1.31 – 6.23
	Poac(lag 4)	1.005	1.002 – 1.009	0.5	0.19 – 0.90
Women	T_{heat}(lag 3)	1.036	1.016 - 1.057	3.5	1.57 - 5.38
	Leqd(lag 0;4)	1.097	1.081 - 1.113	8.8	7.47 - 10.12
	PM$_{10}$(lag 1)	1.020	1.010 - 1.031	2.0	0.97 - 2.99
	Poac(lag 7;15)	1.010	1.005 - 1.015	1.0	0.51 - 1.43

Table 5. Relative risk (RR) and Attributable Risk (AR%) of hospital admissions due to respiratory causes in the Madrid Region.

	Natural causes *Both sexes* *(95%CI)*	*Natural causes* *Women* *(95%CI)*	*Respiratory causes* *Women* *(95%CI)*
Whole period	1275 (276 -2147)	1023 (345 1675)	339 (152 -522)
By heat wave day *(N=198)*	6.4 (1.4 -10.8)	5.2 (1.7- 8.5)	1.7 (0.8 -2.6)
By year (N =9)	141.7 (30.7 -238.6)	113.7 (38.4 -186)	37.7 (16.9 -57.9)

Table 6. Heat-related admissions, by sex, natural causes and specific cause of admission; results shown only for groups and causes in which there is an association with heat.

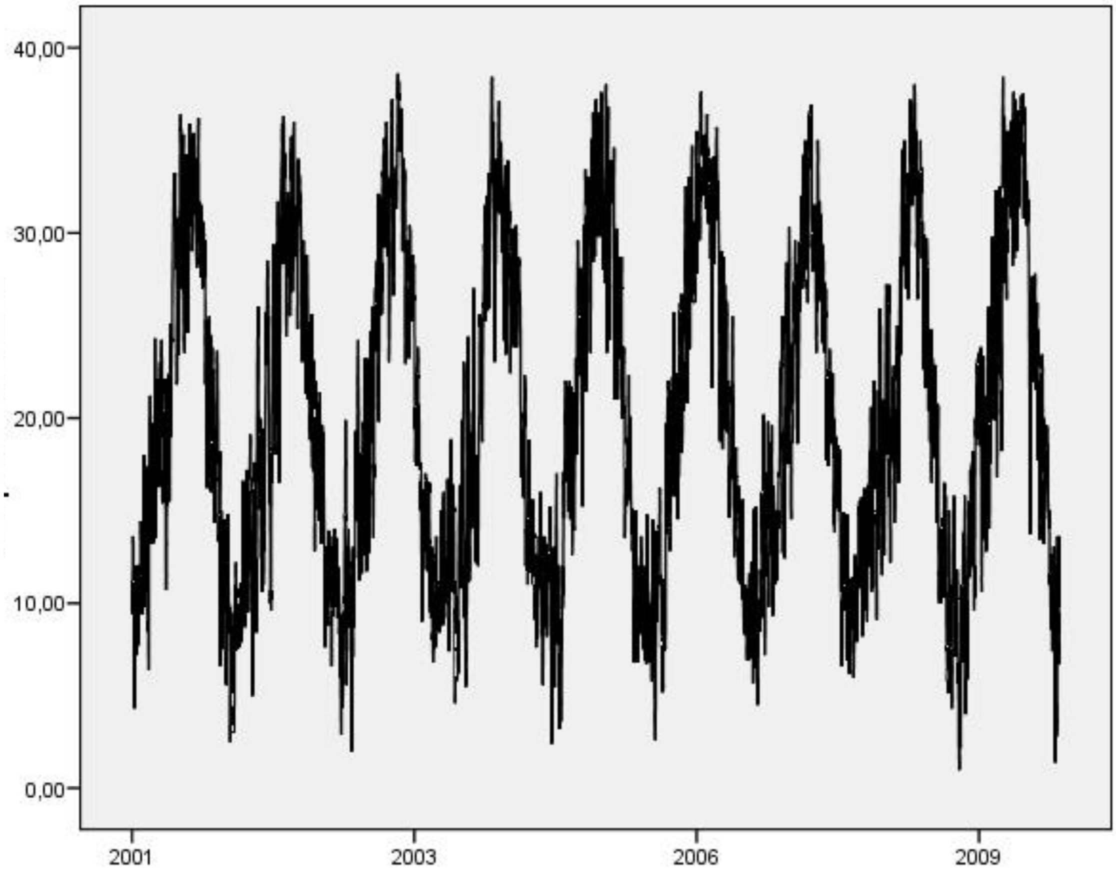

Figure 1. Time series plot corresponding to Maximum temperature (ºC) in Madrid (2001-2009)

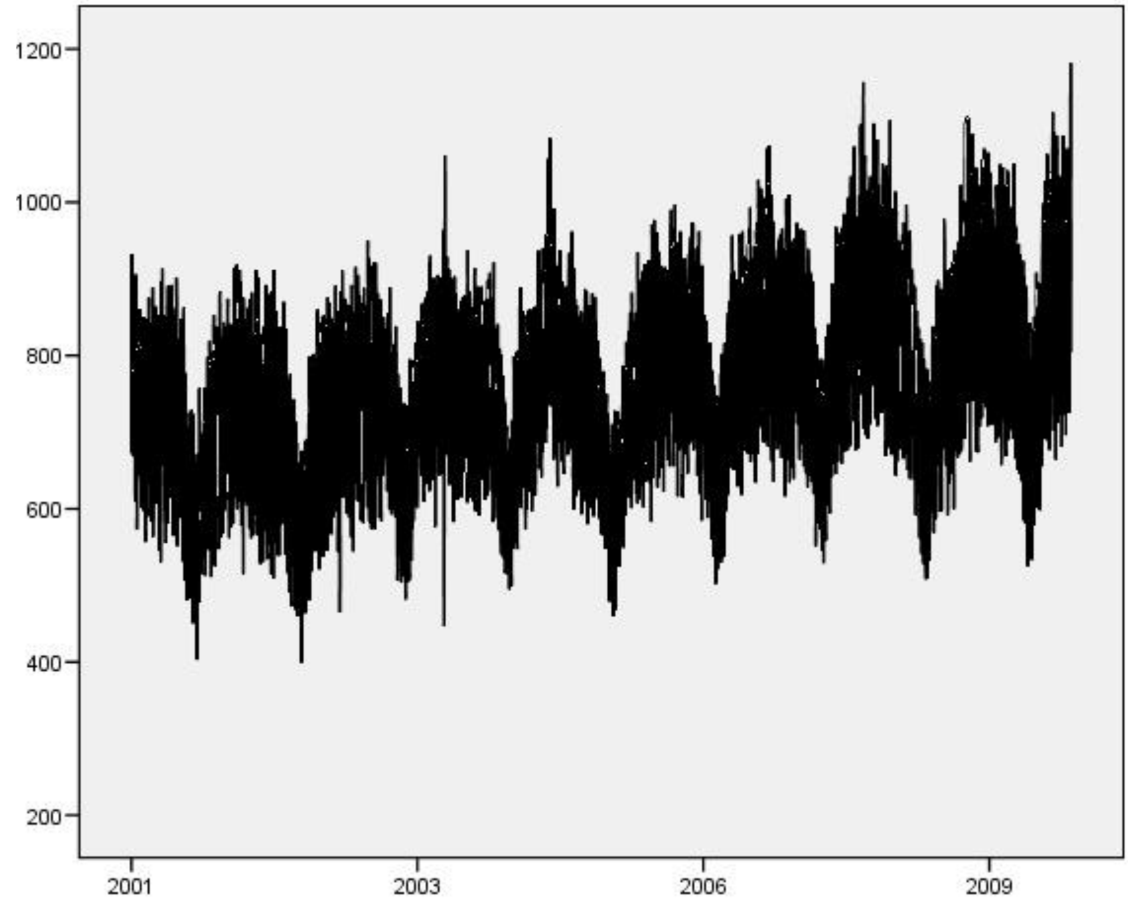

Figure 2. Time series plot corresponding to total hospital admissions by natural causes in Madrid (2001-2009)

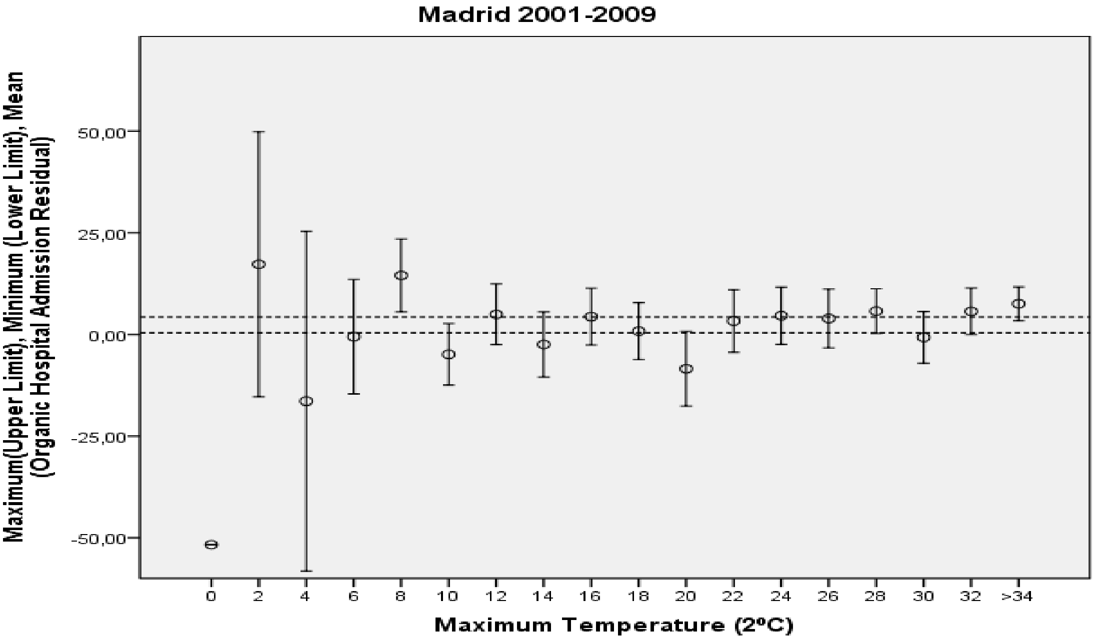

Figure 3. Scatterplot diagram of prewhitened series of hospital admissions and maximum daily temperature (ºC).

- Fewer studies analyse the impact of heat waves on morbidity by gender.
- A decrease was observed in $T_{threshold}$ for heat, which dropped from 36.5ºC in period 1995 - 2000, to 34ºC in 2001 -2009.
- There was no association for circulatory causes, but there was an association only among women for respiratory causes.
- The reduction obtained in the impact of heat on hospital admissions is similar to that obtained for mortality.