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Gender differences in adaptation to heat in Spain (1983–2018)

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ABSTRACT

In Spain the average temperature has increased by 1.7 °C since pre-industrial times. There has been an increase in heat waves both in terms of frequency and intensity, with a clear impact in terms of population health. The effect of heat waves on daily mortality presents important territorial differences. Gender also affects these impacts, as a determinant that conditions social inequalities in health. There is evidence that women may be more susceptible to extreme heat than men, although there are relatively few studies that analyze differences in the vulnerability and adaptation to heat by sex. This could be related to physiological causes. On the other hand, one of the indicators used to measure vulnerability to heat in a population and its adaptation is the minimum mortality temperature (MMT) and its temporal evolution.

The aim of this study was to analyze the values of MMT in men and women and its temporal evolution during the 1983–2018 period in Spain's provinces. An ecological, longitudinal retrospective study was carried out of time series data, based on maximum daily temperature and daily mortality data corresponding to the study period. Using cubic and quadratic fits between daily mortality rates and the temperature, the minimum values of these functions were determined, which allowed for determining MMT values. Furthermore, we used an improved methodology that provided for the estimation of missing MMT values when polynomial fits were inexistent. This analysis was carried out for each year. Later, based on the annual values of MMT, a linear fit was carried out to determine the rate of evolution of MMT for men and for women at the province level.

Average MMT for all of Spain's provinces was 29.4 °C in the case of men and 28.7 °C in the case of women. The MMT for men was greater than that of women in 86 percent of the total provinces analyzed, which indicates greater vulnerability among women. In terms of the rate of variation in MMT during the period analyzed, that of men was 0.39 °C/decade, compared to 0.53 °C/decade for women, indicating greater adaptation to heat among women, compared to men. The differences found between men and women were statistically significant. At the province level, the results show great heterogeneity.

Studies carried out at the local level are needed to provide knowledge about those factors that can explain these differences at the province level, and to allow for incorporating a gender perspective in the implementation of measures for adaptation to high temperatures.

1. Introduction

In Spain the average temperature has increased by 1.7 °C since preindustrial times. This increase has manifest with greater intensity during the past decade (Gobierno de España, 2020). Maximum temperatures have increased between 1983 and 2018 by 0.34 °C/decade, affecting the health of the most vulnerable population groups (Follos et al., 2021; Gobierno de España, 2020; Watts et al., 2018).

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Some of the direct effects of climate change on population health are related to mortality due to extreme temperatures, especially due to heat waves (Watts et al., 2018). It is known that heat waves do not affect the whole population in the same way. Different studies conclude that there is great geographic variability in the effects of heat on daily mortality (Follos et al., 2021; Navas-Martín et al., 2022; Zhao et al., 2021). These geographic differences in population vulnerability to heat could be related to social, environmental and behavioral factors as well as differences in adaptation to high temperatures (Barrett, 2015; Gasparrini et al., 2016).

Other factors that may have an influence include public health prevention plans to address heat in different zones, availability of air conditioning, better health services, insulation of housing and the age of buildings (López-Bueno et al., 2020) as well as climate-related factors such as humidity, which can modify the impact of heat on daily mortality. The percentage of population over age 65, income level, employment rates, and the rural/urban nature of each province may also have an influence (Huertas et al., 2021; López-Bueno et al., 2020).

There is evidence that women may be more vulnerable to extreme heat than men (Follos et al., 2020). Some research has suggested an effect 20 times greater in women (Yu et al., 2010), primarily in people of advanced ages (Folkerts et al., 2021) and due to circulatory system issues (Díaz et al., 2015). This different vulnerability between men and women could be due to physiological and biological causes or gender differences. Among biological and physiological causes, it is notable that women dissipate less heat when sweating (Kaciuba-Uscilko and Grucza, 2001), have thicker subcutaneous fat which makes elimination of heat more difficult, and react to high temperatures with increases in the production of vasoactive substances and in blood viscosity**,** which can change blood flow and blood pressure (Charkoudian et al., 2017; Sorensen et al., 2018). Female hormones influence the regulation of body temperature (Barry et al., 2020; Charkoudian and Stachenfeld, 2014). Both women's menstrual cycles as well as menopause are biological processes that alter women's body temperature (Charkoudian et al., 2017; Charkoudian and Stachenfeld, 2016; Kaciuba-Uscilko and Grucza, 2001; Monteleone et al., 2018). When work is carried out in conditions of extreme heat, it affects men and women differently. While men experience higher rates of heat stroke, women can experience higher rates of other diseases (Kazman et al., 2015).

Some of the differences between men and women due to gender issues could be related to the different roles that men and women play (Kabeer, 2008), differences in access to resources and inequalities in power and in participation in decision making (Gobierno de España, 2020).

One way to quantify adaptation to heat is by evaluating the minimum mortality temperature (MMT) (Folkerts et al., 2020; Yin et al., 2019). MMT can be understood as the temperature at which morality is minimized on the association curve of temperature/estimated mortality (Lee et al., 2017). This MMT coincides with the vertex of the traditional V form in the temperature/mortality relationship (Folkerts et al., 2020; Follos et al., 2020).

Studies carried out in Spain show that, on average, MMT has increased at a rate of 0.57 °C/decade, while maximum summer temperatures have increased at a lower rate, as previously described, indicating an adaptation to heat that is even greater than the increase in the maximum temperature experienced (Follos et al., 2021). It should be noted that there is important geographic heterogeneity (Navas-Martín et al., 2022), probably due to sociodemographic and economic factors (López-Bueno et al., 2021) and ecological and cultural conditions in different locations (Susan Solomon et al., 2021).

Although studies have been carried out on the differences in MMT in different geographic zones (Åström et al., 2016; Chung et al., 2018; Folkerts et al., 2020; Follos et al., 2021), and despite significant evidence on the impact of the different physiological response mechanisms of men and women to high temperatures (Barry et al., 2020; Charkoudian and Stachenfeld, 2014), there are practically no studies that provide results about different behavior and the evolution of MMT in men and women (Follos et al., 2020). Information is needed that provides knowledge about the behavior of MMT at the geographic level.

The aim of this study was to analyze the values of MMT in men and women and their evolution over the 1983–2018 time period in all of the provinces of Spain.

2. Material and methods

2.1. Study variables

An ecological time series study was carried out for the years 1983–2018 in 50 provinces that represent the administrative divisions of Spain. The variables of province code, year and sex were used (corresponding to men and women) for data classification and grouping (Table 1).

2.2. Calculation of MMT

Daily mortality data coded by all causes of death (ICD X: A00-R99) and according to sex occurred in each province during the period considered were used. The corresponding rates per 100,000 inhabitants were calculated from the daily mortality and population data. These data were provided by the National Statistics Institute (INE) through the agreement signed for the transfer of microdata.

With respect to the meteorological data corresponding to maximum daily temperatures, the data recorded for the maximum daily temperature corresponding to the reference observatories in each province were used. These data were supplied by the State Meteorological Agency (AEMET).

Null mortality and temperature records were eliminated, as well as annual series with no more than 10% of valid records.

For each province and for each year, an X_Y diagram was drawn up in which the X axis corresponds to the maximum daily temperature distributed in intervals of 1 °C and the Y axis corresponds to the daily mortality rate occurring in that temperature interval. A quadratic or cubic fit was then performed. The minimum of these functions corresponds to the so-called MMT for that year.

This procedure was carried out for each province and for males and females. In each case, both curves were fit to establish the most appropriate, statistically significant regression (p-value <0.05) (Follos et al., 2020).

2.2.1. Estimation of MMT missing values

In the absence of a significant quadratic or cubic fit, the MMT was estimated as follows. The days on which the daily mortality rate was below the 5th percentile of the series of daily mortality rates occurring that year were determined. The daily maximum temperatures were determined for the days to which these rates corresponded. The average of these temperatures gives the MMT value for that year.

The quality of the MMT values estimated using this approximation were grouped into three levels. First, they were calculated only for those provinces whose TMAX registries were at least 90 percent complete. Second, the concordance of new MMT values with those calculated numerically was analyzed. Finally, those that were not biologically plausible were discarded.

After validating the results, the methodology of imputing lost values provided for an increase of 30 percent in valid observations.

2.3. Determination of the level of adaptation based on the slope of the line representing the temporal evolution of MMT

From the annual values of MMT for each province and for men and women, a linear adjustment was made. The slope of this line represents the annual change in MMT. Multiplying this slope by ten gives the MMT

Table 1
Average of the annual MMT values at the province level for men and women (°C) corresponding to MMT; Average maximum daily temperature corresponding to MEAN (°C); Rate of variation in maximum daily temperature corresponding to TMAX rise (°C/decade); the rate of variation in MMT for men and women corresponding to MMT Variation and Adaptation level, for men and women (°C/decade). Period of analysis: 1983–2018. *p < 0.05.

Province		MMT		Temperature		MMT Variation (°C/decade)		Adaptation level (MMT Variation-TMAX rise)	
Cod	Name	Men	Women	Mean (°C)	TMAX rise (°C/decade)	Men	Women	Men	Women
1	Araba	29.57	27.57	17.4	0.459	−0.643	−1.203	−1.102	−1.662
2	Albacete	29.40	30.29	21	0.509	−0.848	0.189	−1.357	−0.320
3	Alicante	29.73	29.49	23.5	0.19	0.267	0.824*	0.077	0.634
4	Almería	31.28	30.62	23.4	−0.07	0.607	1.242	0.677	1.312
5	Ávila	26.20	26.65	17.2	0.394	0.554	1.551	0.160	1.157
6	Badajoz	32.65	31.56	24	0.286	0.561	1.007*	0.275	0.721
7	Balears, Illes	28.90	27.75	22	0.33	0.716	0.679	0.386	0.349
8	Barcelona	27.03	26.00	20.6	0.414	0.569*	0.311	0.155	−0.103
9	Burgos	27.75	28.61	16.8	0.372	0.812	−0.128	0.440	−0.500
10	Cáceres	31.98	30.11	22.1	0.336	0.855	1.341*	0.519	1.005
11	Cádiz	28.03	27.98	21.7	0.287	0.292	0.490	0.005	0.203
12	Castellón	29.52	28.85	22.5	0.37	0.415	1.198	0.045	0.828
13	Ciudad Real	31.28	28.70	22	0.267	0.404	0.995	0.137	0.728
14	Córdoba	34.71	33.36	25.4	0.332	1.532*	2.293*	1.200	1.961
15	Coruña, A	24.32	23.46	18	0.351	0.333	0.784*	−0.018	0.433
16	Cuenca	29.36	27.19	19.6	0.617	0.292	0.583	−0.325	−0.034
17	Girona	29.11	28.63	21.1	0.656	0.813	1.229*	0.157	0.573
18	Granada	31.20	30.99	22.6	0.416	0.117	0.825	−0.299	0.409
19	Guadalajara	31.15	29.29	20.5	0.367	−1.054	0.939	−1.421	0.572
20	Gipuzkoa	27.18	26.59	16.6	0.244	0.860	0.197	0.616	−0.047
21	Huelva	31.22	30.26	24.1	0.322	2.729*	1.584*	2.407	1.262
22	Huesca	30.56	29.52	19.8	0.489	0.581	−1.178	0.092	−1.667
23	Jaén	31.86	30.07	21.8	0.516	0.644	1.373*	0.128	0.857
24	León	27.51	27.80	16.9	0.243	−0.662	0.345	−0.905	0.102
25	Lleida	31.63	29.85	21.7	0.264	1.152	0.404	0.888	0.140
26	Rioja, La	28.48	27.86	19.8	0.416	0.321	1.766	−0.095	1.350
27	Lugo	28.17	27.63	17.8	0.189	0.069	1.986	−0.120	1.797
28	Madrid	30.60	28.31	20.2	0.394	0.639	0.564*	0.245	0.170
29	Málaga	30.34	31.11	23.5	0.32	1.079*	−0.187	0.759	−0.507
30	Murcia	29.32	29.24	22.4	0.172	1.177*	0.267	1.005	0.095
31	Navarra	29.73	28.09	18.6	0.442	−0.559	−0.161	−1.001	−0.603
32	Ourense	30.66	30.51	21.6	0.457	−0.431	0.944	−0.888	0.487
33	Asturias	25.01	24.48	17.5	0.184	0.586	0.359	0.402	0.175
34	Palencia	28.92	25.32	16.8	0.286	−0.661	0.078	−0.947	−0.208
35	Palmas, Las	30.41	30.32	24.3	0.128	−0.299	0.199	−0.427	0.071
36	Pontevedra	25.54	25.50	19.1	0.099	−0.301	0.731	−0.400	0.632
37	Salamanca	27.83	27.14	19	0.613	0.487	0.857	−0.126	0.244
38	S.C. Tenerife	31.30	30.48	24.7	0.225	−0.454	−1.258*	−0.679	−1.483
39	Cantabria	27.47	26.31	18.7	0.277	−0.607	0.337	−0.884	0.060
40	Segovia	29.18	26.97	18.1	0.298	−0.123	−0.354	−0.421	−0.652
41	Sevilla	34.84	33.03	25.6	0.31	0.956*	0.901*	0.646	0.591
42	Soria	22.97	23.74	17.3	0.28	1.428	0.632	1.148	0.352
43	Tarragona	29.05	27.36	21.3	0.38	0.502	0.145	0.122	−0.235
44	Teruel	30.11	29.45	19.9	0.42	0.637	0.883	0.217	0.463
45	Toledo	31.24	30.64	22.4	0.412	0.020	1.586*	−0.392	1.174
46	Valencia	30.05	29.48	22.9	0.313	0.139	0.769*	−0.174	0.456
47	Valladolid	27.82	26.44	17.8	0.186	−0.100	0.840	−0.286	0.654
48	Bizkaia	28.64	29.36	19.7	0.062	−0.382	−0.651	−0.444	−0.713
49	Zamora	28.66	28.00	19.2	0.491	−0.363	−0.191	−0.854	−0.682
50	Zaragoza	31.53	29.50	21.3	0.472	0.275	0.215	−0.197	−0.257
	(ES)	**29.45**	**28.67**	**20.63**	**0.34**	**0.32**	**0.58**	**−0.02**	**0.25**

variation in °C/decade. Using the same procedure for TMAX its decadal variation was calculated. The result was expressed in degrees/decade (TMAX rise). The ADAPTATION level was obtained from the difference between MMT variation and TMAX rise. Adaptation exists when MMT variation is higher than TMAX rise, i.e. positive values of ADAPTATION level.

Annual MMT values were calculated for males and females in each province (Table 1) according to the methodology described above.

Statistical differences (p-value <0.05) were then determined using a bivariate model (Table 2).

In this model, the dependent variable was MMT and the independent variables were year and sex.

In addition, multilevel linear regression mode was used (Table 3) with adaptation level as the dependent variable and sex as the independent variable.

R software version 4.0.2 was used for the treatment and analysis of the data, as was STATA BE-Basic Edition version 17, IBM SPSS Statistics version 27 and Excel (with the Power Query editor) from the Microsoft

Table 2
Bivariate model for MMT with sex and year variables.

MMT	Coef.	Std. Err.	z	P > z	[95% conf. interval]
Year	0.047	0.007	6.35	0.000	0.033 0.062
Sex	−0.784	0.155	−5.06	0.000	−1.088–0.481

Table 3
Multi-level linear regression model of adaptation by province based on sex.

ADAPTATION Level	Coef.	Std. Err.	z	P > z	[95% conf. interval]
Sex	0.047	0.007	6.35	0.000	0.0328 0.062

Office Professional Plus 2019 package.

3. Results

Due to gaps in the daily mortality or Tmax series of the 3600 possible MMT values, a total of 2662 MM were calculated, of which 1650 (62.0%) correspond to a cubic adjustment; 860 (32.3%) to estimation and 152 (5.7%) to quadratic adjustment.

Table 1 shows the values of MMT at the province level for men and women during the 1983–2018 period (°C), the average maximum daily temperature (TMAX) (°C), the rate of variation in maximum daily temperature (°C/decade), and the rate of variation in MMT for men and women. The final column shows the level of adaptation to high temperatures for men and women (° C/decade), considering that positive values indicate that MMT has increased more rapidly than has TMAX, that is to say, there has been adaptation. Negative values signify that MMT has increased less than has TMAX, thus, there has not been adaptation. The final row of the table shows the average values for all of Spain. The average maximum daily temperature in Spain was 20.6 °C, with an increasing trend across time of 0.34 (°C/decade).

At the province level the values of MMT were higher for men in 86 percent of the provinces, with an average value for the whole country of 29.4 °C in the case of men and 28.7 °C in the case of women. However, the rates of variation in TMM were greater in the case of women than of men, given that in 62 percent of Spanish provinces this rate was higher in women. In order to know whether these differences were statistically significant, bivariate models were developed for MMT, including the variables year and sex, as shown in Table 2. The results indicate that the annual variation in MMT was significant as were the differences found by sex.

Fig. 1 shows the MMT regression lines for the whole of Spain. It can be seen that the rate of growth in MMT for men was 0.39 °C/decade, while for women it was 0.53 °C/decade. According to Table 1, TMAX has grown during the studied period at a rate of 0.34 °C/decade. Thus, it can be said that both sexes have adapted to high temperatures, and that this adaptation has been much clearer in the case of women.

At the province level, Table 1 shows that 68 percent of the provinces evidence adaptation among women, compared to 52 percent among men. In 40 percent of provinces there has been adaptation among both men and women. The values of the adaptation variable by sex show differences that are statistically significant, as can be seen in the results of the multi-level linear regression that appear in Table 3.

Fig. 2 shows various examples of the regression lines and the rate of growth of MMT throughout the 1983–2018 time period in the provinces of Córdoba, Barcelona and A Coruña.

Figs. 3 and 4 show a dispersion diagram in which the x-axis shows the rate of variation in maximum daily temperature, and the y-axis shows the rate of increase in MMT. The shaded zone shows those values for which the rate of variation in MMT surpasses the increase observed in TMAX; such values signify adaptation. Fig. 3 represents men, and Fig. 4 represents women. It can be observed in both figures that there is great geographic heterogeneity at the province level, and a greater number of provinces evidence adaptation of women, compared to men.

4. Discussion

This research was a study of the evolution of MMT between 1983 and 2018 in terms of the level of adaptation by gender in each of Spain's provinces. Prior studies have analyzed the adaptation of MMT in different provinces of Spain, without focusing on gender differences or other socioeconomic variables (Follos et al., 2021). In the present study, a greater number of MMT values were included than was the case in Follos et al. for the general population. This inclusion of more MMT values is the reason why the rate of change in MMT obtained here -both in the case of men (0.39 °C/decade) as well as women (0.53 °C/decade)- are slightly different from those obtained for the general population, which established this value at 0.64 °C/decade.

On the other hand, there are few studies around the world that evaluate the vulnerability to climate change based on gender (McCall et al., 2018). The results of our study show relevant information related to the adaptation of the Spanish population to the increase in temperature that has occurred over the past 30 years. The following findings are worth highlighting:

4.1. Women are more vulnerable to heat

As shown previously, the average MMT in the whole of Spain was greater among men than among women (men: 29.4 °C; women: 28.7 °C), and this occurred in 86 percent of the provinces.

This finding is consistent with various prior studies carried out at the

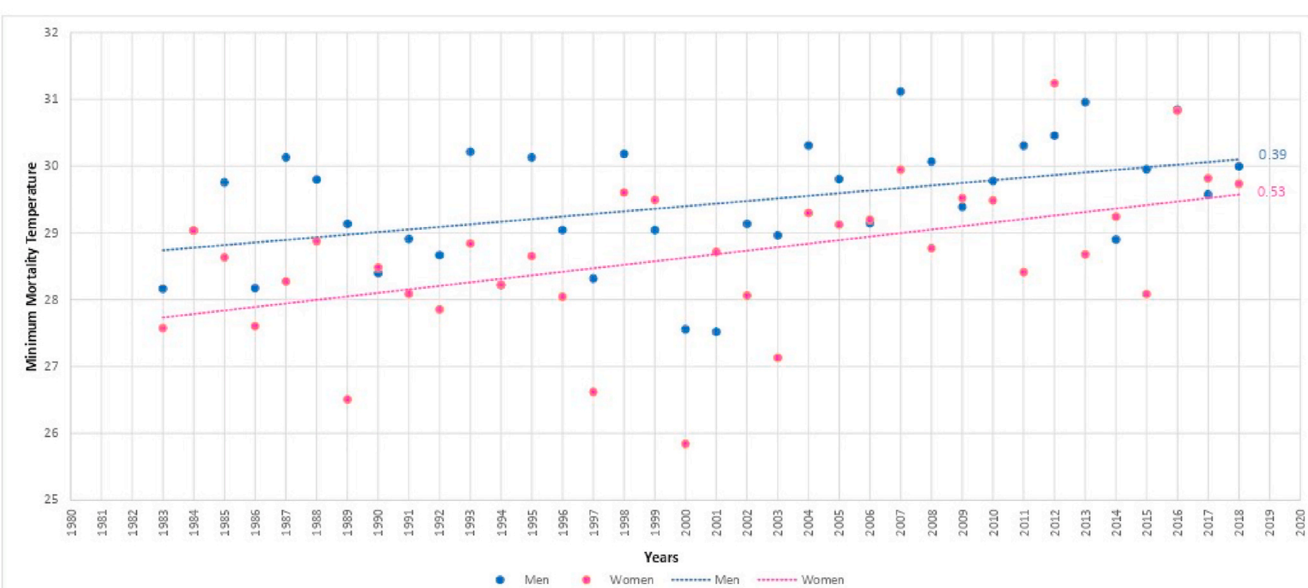

Fig. 1. Evolution of the minimum mortality temperature (MMT) by year in men and women in Spain (1983–2018). See the values of the slopes of the regression lines to the right (°C/decade).

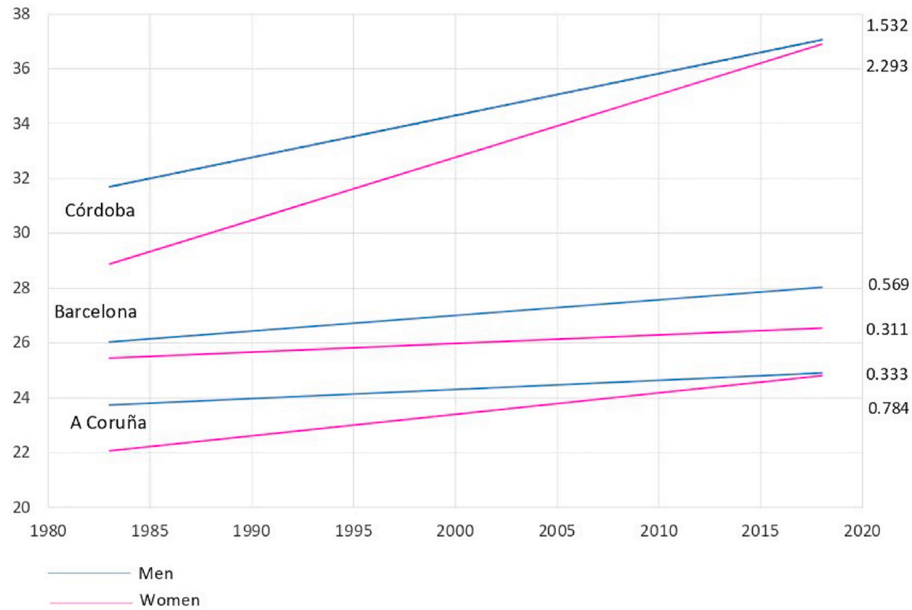

Fig. 2. Linear fits for the minimum mortality temperatures (MMT) in the provinces of A Coruña, Barcelona and Córdoba for men and women (1983–2018). See the values of the slopes of the regression lines by sex for the different provinces (°C/decade) to the right.

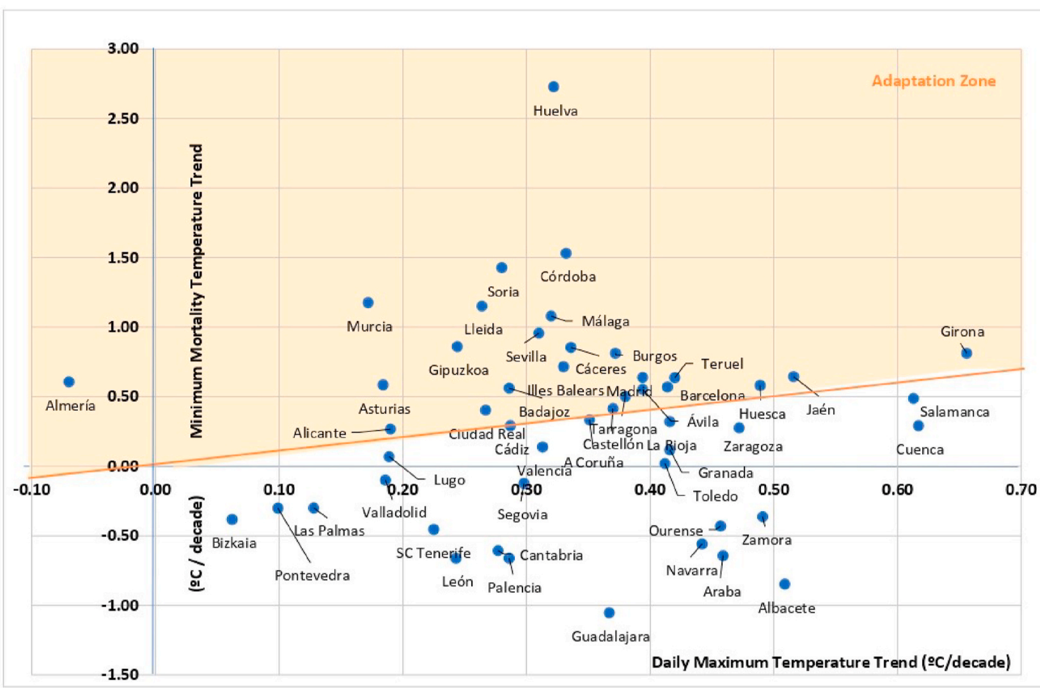

Fig. 3. Dispersion diagram of the minimum mortality temperature (MMT) with respect to the variations in maximum daily temperatures for men in Spain (1983–2018). The shaded area represents those provinces in which there was adaptation to heat.

regional and national levels.

For example, several studies conducted in Spain, found greater MMT values in men when analyzing cardiovascular mortality (Achebak et al., 2019) and mortality from circulatory and respiratory causes (Achebak et al., 2018). On the other hand, some studies carried out in Madrid have shown that women present greater risk, both in terms of death as well as hospital admissions due to natural causes, during a heat wave (Díaz et al., 2018; García-Herrera et al., 2005). Also, in Barcelona that women showed a higher relative risk of mortality compared to men with summer temperature extremes (Ingole et al., 2020). Two other regional studies carried out in Cantabria and Galicia (Northern Spain) found greater sensitivity to high temperatures among women (DeCastro et al., 2011; Gómez Acebo et al., 2011). Research studies carried out outside Spain have also reported greater heat-related mortality among women than among men (Folkerts et al., 2021; Kuchcik, 2021; Son et al., 2011; Stafoggia et al., 2006).

There are various physiological mechanisms that could explain this greater vulnerability to high temperatures among women, including lower heat evaporation through sweat, greater presence of adipose tissue (body fat) and decreased peripheral blood perfusion (Gagnon and Kenny, 2012; Kaciuba-Uscilko and Grucza, 2001). This vulnerability increases after menopause, as the lack of estrogen production makes it

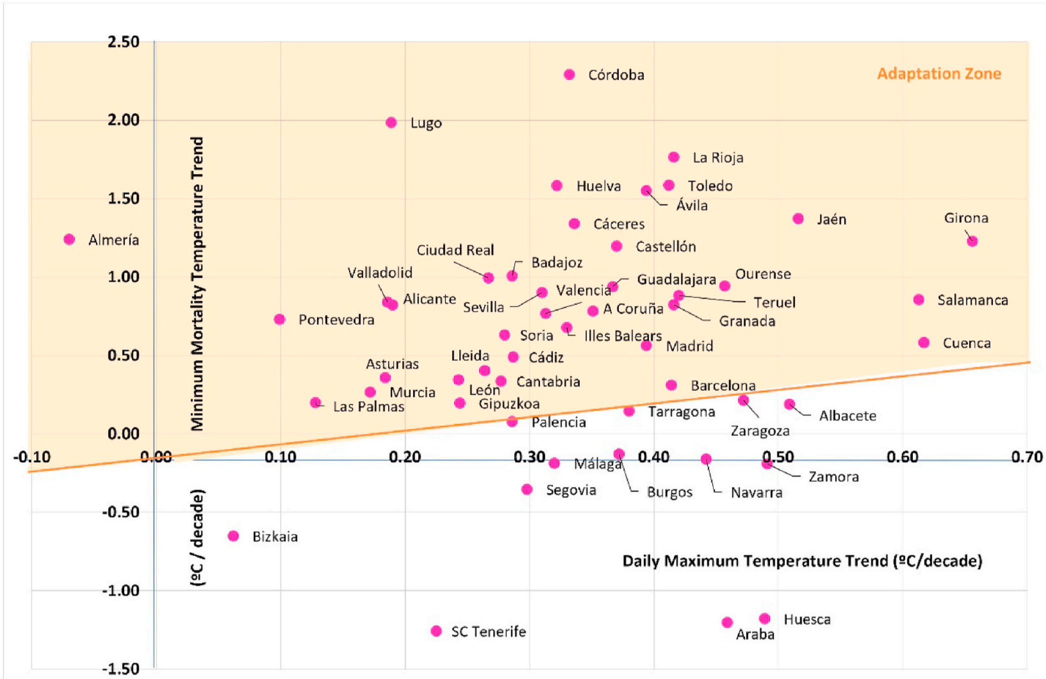

Fig. 4. Dispersion diagram of the minimum mortality temperature (MMT) with respect to variations in the maximum daily temperatures of women in Spain (1983–2018). The shaded area represents provinces in which there was adaptation to heat.

more difficult to adapt to sudden temperature increases (Charkoudian et al., 2017), given that estrogen could favor the activation of thermoregulatory centers which contribute to the dissipation of heat (Székely and Garai, 2018). Furthermore, for women to reach the same physiological adaptation to heat as men, they require greater intensity, frequency and duration of the exposure to heat (Wickham et al., 2020).

It is also important to note that other research has not found significant differences that identify which sex would be more vulnerable. This is the case in a systematic review and meta-analysis that evaluated women's vulnerability to heat and whose authors observed a lower risk among men. However, these results were not significant (Benmarhnia et al., 2015).

4.2. *There is greater adaptation to heat among women than among men*

According to our results, during the study period MMT among women grew at a more rapid rate than among men (0.53 °C/decade vs 0.39 °C/decade). This result was similar in 66 percent of the provinces.

Although there are few studies related to the adaptation to heat by sex, there are a few studies that coincide with the results found here.

Similar results have been found previously in Spain in the provinces of Seville and Madrid (Follos et al., 2020). On the other hand, a study carried out in Kuwait suggested that men are more vulnerable during a heat wave and have worse adaptation to variations in temperature than women (Alahmad et al., 2020). Other studies indicate that local factors may have a role in explaining the different adaptation levels of the sexes (Bell et al., 2008).

4.3. *Other factors are important, including great geographic variability*

The results shown in Figs. 3 and 4 and Table 1 indicate that there is great geographic heterogeneity in the adaptation of the sexes, as has been shown at the level of the whole population (Follos et al., 2021). In general terms, a good part of the provinces located in the South and East of the Mediterranean Peninsula (Mediterranean zone) show greater adaptation than those located in the country center, the North and in the Canary Islands. In other words, those provinces that tend to experience higher temperatures show greater adaptation. This pattern could be related to findings from human physiology studies that focus on acclimatization to heat (Tyler et al., 2016). It could also be explained by technological adaptation, mainly with the prevalence of air conditioning equipment being higher in the southern regions of Spain, which have more air conditioning than in the north (Instituto Nacional de Estadística, 2008). The provinces with a lower level of adaptation in Spain include Guadalajara, Araba and Albacete for men and Tenerife, Araba and Huesca for women.

Future studies should investigate the sociodemographic issues that could imply greater vulnerability to climate change and global warming, such as migration, urban-rural disruption, socioeconomic level (Gouveia et al., 2003) and age (Benmarhnia et al., 2015; van Steen et al., 2019). This could bring clarity to some of the findings observed in this study, where it was shown that in some provinces there is a greater level of adaptation among men, despite that in general terms women seem to adapt much better to increasing global temperatures.

Studies should be carried out that include a gender perspective that promotes gender equality and women's empowerment, given that the United Nations promotes both the Sustainable Development Objectives as well as climate action (United Nations, 2020; Desai & Zhang, 2021). In terms of global warming, human beings utilize different adaptation mechanisms to address temperature increases. These mechanisms can be grouped based on sex and gender. Sex is related to the biological and physiological characteristics of human beings, while gender relates to social constructive characteristics, such as roles, behaviors, attributes and activities that are considered to be related to being a man or a woman. This is an important difference, because sex is determined by biological differences, while gender is determined by society (Charkoudian and Stachenfeld, 2014). However, differences in mortality and disease may be due in part to biological sex differences. In contrast, explanations for biological differences are limited in explaining different health outcomes by sex. These could be explained by the social phenomenon of gender (Manandhar et al., 2018). Therefore, this allows us to establish two large groups of adaptation mechanisms: those that are determined by sex (physiological adaptation) and those that are determined by gender (behavioral, cultural and constructive characteristics).

Physiological adaptation or acclimatization refers to mechanisms related to the human body, for example, the production of sweat (Mcgregor et al., 2019). Behavioral adaptation is determined by the way we behave, for example, the way we dress (Nakagawa and Nakaya, 2021; Weitensfelder and Moshammer, 2020) or the way we eat. There is also cultural adaptation, for example, the way we organize work or rest. Finally, constructive adaptation refers to aspects such as housing as a means of protection (Weitensfelder and Moshammer, 2020). Environmental and behavioral adaptation in buildings, e.g., workplaces, differ depending on the weight, age and gender of the occupants (Indraganti et al., 2015). In general, women prefer higher ambient temperature at home and in the workplace than men. This difference in thermal acceptability and temperature comfort could be explained as indoor climate regulations are based on standard values in men without taking women into account in the design of theoretical models (Kingma and van Marken Lichtenbelt, 2015).

The results found here related to adaptation to heat related to gender may be modulated primarily by social mechanisms that generate differences between men and women, such as socioeconomic differences, access to production resources (Chanana-Nag and Aggarwal, 2020), and access to technology and information. For example, in Pakistan poor women do not have access to television and radio and depend on men to be informed about public service announcements (Susan Solomon et al., 2021).

4.4. Study limitations

This study presents some limitations. First, the sources of primary data used were not completely representative for all years and provinces, as there was scarce information available for certain provinces. Although it was not possible to analyze the total number of registrations due to methodological reasons mentioned previously, the use of a combined methodology in calculating MMT resulted in an increase in valid data and greater representativeness of the results compared to prior studies (Follos et al., 2021). The absence of 26 percent of the registrations had an influence, in some cases, in the evolution of MMT, and specifically that it did not show significant differences in a greater number of provinces.

Second, given that this was an ecological time series study, the results cannot be extrapolated at the individual level (Morgenstern, 1995). In addition, given that we used data at the province level, we were unable to know the potential impact of MMT related to the urban-rural gradient, which varies based on demographic, social and cultural differences in each province. Therefore, local level characteristics should be explored with greater depth to identify the most appropriate adaptation strategies (Park et al., 2019), taking into account the great heterogeneity found in prior studies on the impact of heat on populations at the national level (Follos et al., 2021; Navas-Martín et al., 2022) and even at the municipal level (López-Bueno et al., 2020).

Finally, there is no universal methodology for relating mortality attributable to temperature. Many studies have addressed the climate sensitivity of health and its potential impact in different parts of the world and with different methods (Baccini et al., 2011; Błażejczyk et al., 2017; Hayhoe et al., 2010; Honda et al., 2014; Laschewski and Jendritzky, 2002; Rocklöv et al., 2011). Although the results found with respect to women's vulnerability to heat are consistent with other studies carried out in Spain and other countries. Despite these methodological differences in relating mortality to temperature, the use of the MMT as an indicator to determine the level of adaptation of a given population is recommended.

5. Conclusions

MMT values were greater in men compared to women, which indicates greater vulnerability of women to high temperatures. Even though MMT increased for both sexes over time, the rate of increase in MMT was greater in women than in men. Therefore, we can say that women in Spanish provinces have better adapted to heat than men. The differences found were statistically significant.

On the other hand, the estimation of missing values for MMT permitted greater representativeness in the analysis, using more precise indicators.

Finally, due to the differences found in levels of adaptation in the different provinces, local level studies are needed in order to know which factors are keys to reducing social inequalities in health, and which therefore can allow for application of adaptation measures that include a gender perspective.

Credit author statement

Miguel Ángel Navas-Martín. Original idea of the study. Study design; Providing and Analysis of data; Elaboration and revision of the manuscript. José Antonio López-Bueno. Providing and Analysis of data; Elaboration and revision of the manuscript. María Soledad Ascaso-Sánchez. Providing and Analysis of data; Elaboration and revision of the manuscript. Rodrigo Sarmiento-Suárez. Providing and Analysis of data; Elaboration and revision of the manuscript. Fernando Follos. Providing and Analysis of data; Elaboration and revision of the manuscript. José Manuel Vellón. Providing and Analysis of data; Elaboration and revision of the manuscript. Isidro Mirón. Providing and Analysis of data; Elaboration and revision of the manuscript. Yolanda Luna. Providing and Analysis of data; Elaboration and revision of the manuscript. Gerardo Sánchez-Martínez. Study design; Elaboration and revision of the manuscript. Dante Culqui. Providing and Analysis of data; Elaboration and revision of the manuscript. Cristina Linares. Original idea of the study. Study design; Elaboration and revision of the manuscript. Julio Díaz. Original idea of the study. Study design; Elaboration and revision of the manuscript.

Disclaimer

The researchers declare that they have no conflict of interest that would compromise the independence of this research work. The views expressed by the authors do not necessarily coincide with those of the institutions they are affiliated with.

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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