Geographical and climatic factors and depression risk in the SUN project

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Background: Depression incidence has been related with seasonal periodicity and climate. The aim of the study was to estimate the possible association between depression and specific meteorological factors, namely temperature, light and rain. Methods: In total, 13 938 participants from the SUN (Seguimiento Universidad de Navarra) cohort study were included in the analysis. Subjects were classified according to daily mean temperature, number of daylight hours and amount of rain, by year, at their geographical area of residence, data supplied by the Spanish Agency of Meteorology. Participants were considered as incident cases of depression whenever they reported a physician diagnosis of depression or the use of antidepressant medication in any of the follow-up questionnaires. Cox regression models were fit to assess the relationship between climatic and geographical factors and the incidence of depression. Results: Male subjects living in the south and centre areas of Spain showed a higher risk to develop depression compared with those living in the north area (hazard ratio = 1.6, 95% CI = 1.16–2.23 and hazard ratio = 1.41, 95% CI = 1.06–1.87, respectively). Moreover, among males, a direct association between the number of daily light hours and mean temperature and the risk of depression was also found. For men, living in rainy areas was associated with a lower risk of developing depression. Conclusion: Our results suggest that climate-depression relationship is more complex than previously thought, and strongly different between men and women.

Introduction

Seasonal influence on human behaviour has been deeply studied both at the physical and mental domain.

Prevalence of depression disorders is more frequent in those populations living in higher latitude areas.1 The shorter period of daily light time in these areas has been suggested as an explanatory factor for the differences in the prevalence of the disease among different latitude areas.2,3

In addition, it has been reported that individuals living in higher latitudes are more vulnerable to seasonal changes compared with those living in tropical areas, on the basis of the strong correlation between temperature change and pattern of seasonal depression symptoms.4
Therefore, the depression seasonal model has been intensively studied during the past years. Although initially it was considered that depression prevalence was higher during the winter and autumn months, nowadays there is discrepancy and the evidence is not enough. Whereas several researchers have reported a higher frequency of depression during the winter months, others have concluded that it is during summer and/or autumn months when the prevalence of the disease is more important. Finally, some studies have also reported no association between depression prevalence and the season of the year. Additionally, studies based on women who have newly given birth have found a higher frequency of postpartum depression during the winter months.

In the past few years, new therapeutic strategies aimed to increase antidepressant efficacy and based on supplemental light therapy have been suggested. These new therapeutic strategies have showed their effectiveness on non-seasonal depression.

Our study aim was to analyse the relationship between the meteorological characteristics that define typical Spanish areas climate and the incidence of depression among the participants of the SUN cohort study.

**Methods**

**Subjects**

The SUN Project (Seguimiento Universidad de Navarra—University of Navarra Follow-up) is a multipurpose dynamic (open-recruitment) cohort study of Spanish university graduates started in 1999. The cohort profile and its methodology has been published in detail elsewhere. Information is gathered through postal and web-based questionnaires sent every 2 years.

Up to March 2009, 19,837 participants had completed the baseline questionnaire. To our purposes, we excluded 1925 participants lost to follow-up, 2118 diagnosed cases of depression at recruitment, 37 participants with incomplete depression and/or place of residence data as well as 1819 participants having reported total energy intake values out of pre-specified limits (<800 or >4000 kcal/day for men, <500 or >3500 kcal/day for women). Finally, 13,938 participants were included in the analysis (figure 1).

The study was approved by the University of Navarra Human Research Ethical Committee. Informed consent was considered implicitly given after having carried out the first questionnaire.

**Exposure assessment**

Data about climatic factors were provided by the Spanish Agency of Meteorology (www.aemet.es). This agency provides yearly data of mean temperature, number of daylight hours and amount of rain of the different observatories in each region (autonomous community) of Spain. We calculated the mean daily temperature and the total amount of daylight hours and rain for each Spanish region for the 1971–2000 periods (see Supplementary Appendix). Finally, continuous variables were categorized into tertiles.

Area of residence (geographical localization) was classified into three areas: North (Galicia, Asturias, Cantabria, País Vasco, Navarra, La Rioja y Cataluña), Centre (Aragón, Castilla-León, Madrid, Castilla la Mancha, Comunidad Valenciana y Baleares) and South (Murcia, Extremadura, Andalucía, Canarias y Ceuta y Melilla).

**Outcome assessment**

Participants were classified as incident cases depression when they were free of depression and antidepressant treatment at baseline and positively responded to the question, “Have you ever been diagnosed as having depression by a medical doctor?” or who reported an habitual use of antidepressant drugs in any of the follow-up questionnaires.

**Covariates assessment**

Socio-demographic (age, sex and employment status) and anthropomorphic (weight, height and body mass index, BMI) variables, and lifestyle and health-related habits (smoking status, leisure-time physical activity, diet and adherence to the Mediterranean pattern), were collected at baseline. Physical activity was assessed through a validated physical activity questionnaire. Adherence to the Mediterranean Dietary Pattern, which has been argued plays a protective role, was assessed combining nine items (fruits and nuts, vegetables, fish, legumes, cereals, ratio monounsaturated/saturated fatty acids, meat and meat products, dairy and alcohol intake) as Prof. Trichopoulou proposes. Moreover, the prevalence of cardiovascular disease and several metabolic conditions at baseline was also ascertained, on the basis of the proposed shared physiopathological mechanisms.

In addition, data on gross domestic product and unemployment rate within each Spanish region in 2001 were also collected from the INE (Instituto Nacional de Estadística, National Institute of Statistics).

**Statistical analysis**

Cox (proportional hazards) regression models were fit to assess the relationship between geographical and climatic factors and the incidence of depression. Hazard ratios (HRs) and their 95% CIs.
were calculated with the north geographical localization and the lowest tertiles of climatic factors as the reference categories.

Tests of linear trend across increasing tertiles of temperature, daylight and rain were conducted by assigning the medians to each tertile; this variable was treated as continuous. Participants contributing the follow-up period up to the date of death, diagnosis of depression or fulfilment date of the last follow-up questionnaire, 2010, whichever came first. Potential confounders included in the multiple-adjusted model, based on alleged relevancy, were sex, age (years), BMI (kg/m²), physical activity levels (tertiles), smoking status (non-smokers, ex-smokers, smokers and missing), unemployment status (no/yes), energy intake (kcal/d), adherence to the Mediterranean diet (quintiles) and the prevalence of cardiovascular disease (no/yes). Changes >20% in HR estimation were considered relevant. The results were also adjusted for several macroeconomic factors such as gross domestic product (purchase power standard, pps) and unemployment rate (%) within each Spanish region.

We finally analysed interactions between sex and geographical and climatic factors, and conducted further sensitivity analyses by stratifying our sample by sex.

All *P* values presented are two-tailed; *P* < 0.05 was considered statistically significant. The SPSS software package for Windows version 19.0 (SPSS Inc., Chicago, IL) was used for statistical analyses.

**Results**

Table 1 shows participants’ characteristics according to their geographical area of residence. Women predominated in Central and Northern areas. Participants living in the Southern area were older, physically more active, non-smokers and showed a higher prevalence of cardiovascular diseases despite its high adherence to the Mediterranean diet.

The association between geographical location and depression risk is shown in table 2. It is observed a higher risk in the Centre area in relation to the North. Considering the autonomous communities, a higher risk is only observed in Castilla La Mancha-Madrid.

The results did not change after adjusting the results additionally for marital status and for the prevalence of hypertension, dyslipidemia or type 2 diabetes mellitus (data not shown). When several macroeconomic factors such as gross domestic product and unemployment rate within each Spanish region were included in the models, the results were slightly modified for the association between location and depression [North (ref.); Centre: 1.20, 95% CI = 1.02–1.42; and South: 1.33, 95% CI = 0.99–1.80], disappearing the higher risk previously found in Castilla La Mancha-Madrid.

The association between climate and depression risk is shown in table 3. People living in areas with more daily light hours and higher temperature mean values showed a statistically higher risk of depression than those living in shady and cold places. (HR for the highest tertile of light hours vs. the lowest tertile = 1.29, 95% CI = 1.08–1.54; HR for the highest tertile of temperature vs. the lowest tertile = 1.31, 95% CI = 1.09–1.56). Moreover, a direct dose–response relationship was observed for temperature and number of daily light hours and depression. However, living in an area with the highest rainfall was associated with an important decrease in the risk of developing depression (>1246 m² per year, relative risk reduction 23%; >721 m² per year, relative risk reduction 17%).

Considering the same additional factors used previously for the relation between location and depression risk (data not shown), results only changed after adjustment for macroeconomic factors for temperature [T1 (ref.), T2: 1.09, 95% CI = 0.91–1.31; T3: 1.48, 95% CI = 1.19–1.85].

As the interaction terms geographic localization × sex and temperature × sex with regard to depression risk were statistically significant, the results were repeated after stratification of the sample by sex (table 4). When sex was taken into account, the direct association between daylight hours and temperature values and depression risk only remained among males.

For men, it must also be mentioned that their risk varied according to area of residence: using Northern area as a reference, men living in the Central area had an HR = 1.41 (95% CI = 1.06–1.87), meanwhile those living in the Southern area showed a HR = 1.60 (95% CI = 1.16–2.23).

**Discussion**

Our results contradict the common belief that depression risk increases in those areas with the most adverse weather conditions, i.e. coldest, rainiest and with the lowest number of sunny daily hours, being, however, true that our finding was restricted to men.

To our knowledge, there are only a few epidemiological studies that had studied the association between climate and depression

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**Table 1** Baseline characteristics of the participants from the SUN Project according to their geographical localization

<table>
<thead>
<tr>
<th>Variables</th>
<th>North</th>
<th>Centre</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (% men)</td>
<td>39.7</td>
<td>44.1</td>
<td>49.2</td>
</tr>
<tr>
<td>Age at baseline (years), mean (SD)</td>
<td>37.6 (11.6)</td>
<td>40.1 (12.3)</td>
<td>40.6 (11.9)</td>
</tr>
<tr>
<td>BMI (kg/m²), mean (SD)</td>
<td>23.3 (3.4)</td>
<td>23.7 (3.5)</td>
<td>24.4 (3.7)</td>
</tr>
<tr>
<td>Leisure time physical activity (Met-h/w), mean (SD)</td>
<td>21.5 (22.6)</td>
<td>20.9 (22.1)</td>
<td>22.0 (22.7)</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-smoker (%)</td>
<td>47.2</td>
<td>44.4</td>
<td>48.6</td>
</tr>
<tr>
<td>Ex-smoker (%)</td>
<td>29.1</td>
<td>31.5</td>
<td>31.3</td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>21.3</td>
<td>21.8</td>
<td>19.4</td>
</tr>
<tr>
<td>Unemployed (%)</td>
<td>4.5</td>
<td>3.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Prevalence of cardiovascular disease (%)</td>
<td>3.8</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Total energy intake (kcal/d), mean (SD)</td>
<td>2368.0 (611.8)</td>
<td>2364.6 (616.4)</td>
<td>2271.1 (645.9)</td>
</tr>
<tr>
<td>Mediterranean dietary score (0–9)</td>
<td>4.2 (1.5)</td>
<td>4.4 (1.8)</td>
<td>4.4 (1.8)</td>
</tr>
<tr>
<td>Macroeconomic data*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross domestic product (pps)</td>
<td>103.9 (16.6)</td>
<td>102.2 (17.1)</td>
<td>75.9 (9.6)</td>
</tr>
<tr>
<td>Unemployment rate (%)</td>
<td>7.7</td>
<td>7.7</td>
<td>14.8</td>
</tr>
</tbody>
</table>

North: Galicia, Asturias, Cantabria, Pais Vasco, Navarra and Cataluna.
Centre: Aragon, Castilla Leon, Castilla La Mancha, Madrid, Comunidad Valenciana and Baleares.
South: Extremadura, Andalucia, Murcia, Canarias, Ceuta and Melilla.

incidence. In some cases, it has been reported a significant inverse association between minutes of sunshine, global radiation, length of daylight and temperature and depressive symptoms. However, it has also been reported no association between weather conditions and blue mood or depression.

The fact that we have found a higher depression incidence in areas with higher mean temperatures and length of daylight and lower rainfall is somehow striking on the basis that light is a powerful neurobiological agent and its role as a major synchronizer of the circadian rhythm has been clearly established. Even more, light therapy efficacy both for non-seasonal and seasonal depressions is beyond doubt.

Certainly, there are other factors related to circadian rhythms, such as those related to environment and lifestyle. Air pollution has been consistently associated with an increase in mortality, pulmonary and cardiovascular diseases hospitalization rates and a rise in depressive symptoms. Several mechanisms have been invoked to explain the relationship between air pollution and depression risk such as pro-inflammatory factors induction, oxidative stress and neuro-transmitters system dysfunction. Those mechanisms are also involved in other chronic conditions, such as the cardiovascular disease, whose prevalence is also higher in the Southern area of Spain similarly to depression incidence. Consequently, we might not rule out an eventual role of air pollution in the risk of incident depression in our study.

Even though our cohort is a homogeneous population of University graduates that share social and educational characteristics, and thereby this fact allows us to assume no effects of economic and cultural differences, it may be also possible that differences in social support-related constructs could have also influenced the geographical patterns found in depression incidence.

Regarding as well lifestyle, and taken into account that Vitamin D blood levels correlate positively with sun exposition, it is arguable that it would not be a determining factor for our findings, not to mention that its role in depression has not been clearly established.

Some potential limitations of our study need to be addressed, such as the self-reporting of a clinical diagnosis or the use of medication to define an incident case of depression. However, because participants were highly educated and committed to collaborate, we assumed that the proportion of misreporting the diagnosis...
would be low. Moreover, the validity of self-reported depression diagnosis has been ascertained in a subsample of our cohort. It seems probable, on the basis of low sensitivity and very high specificity, we have underestimated true cases non-differentially, and therefore that our estimate is non-biased.

Regarding the area of residence of the participants, we have to take into account that this information was collected at baseline, and therefore location shifts could have also influenced the results.

Finally it has to be taken in account the effect of the ecological fallacy owing to the collection of climate information at an aggregate level, as well as the potential influence of subtle differences in adjacent zones into any specific area. Regarding the former, we acknowledge that the use of a multilevel model would have been a more appropriate choice to deal with data having been measured at different levels, i.e. individual, group and spatial levels.

In any case, and taking into account not only the consistent negative association found between temperature or daylight hours and depression but also the differences between men and women, the need for new studies aimed to ascertain determinants for geographical patterns is warranted.

### Supplementary data

Supplementary data are available at EURPUB online.

### Acknowledgements


### Key points

- The prevention of mental disorders is a priority owing to their huge health, social and economic burden.
- Relatively scarce scientific evidence exists to assess the association between depression and climate.
- Those living in areas with more daylight hours and higher temperature showed a higher risk of depression. According to our results to live in rainy places could protect against depression.
- New longitudinal studies aimed to ascertain the role of meteorological factors in depression are warranted to provide more definitive answer to the associations found in this study.

### References


### Table 4 Association between geographical situation, climatic variables and risk of depression separately in men and women

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographical localization</td>
<td>Cases</td>
<td>Person-years</td>
</tr>
<tr>
<td>North</td>
<td>147</td>
<td>25343</td>
</tr>
<tr>
<td>Centre</td>
<td>74</td>
<td>8794</td>
</tr>
<tr>
<td>South</td>
<td>48</td>
<td>4828</td>
</tr>
<tr>
<td>Daylight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1: 1708 h per year</td>
<td>73</td>
<td>13276</td>
</tr>
<tr>
<td>T2: 2201 h per year</td>
<td>86</td>
<td>13841</td>
</tr>
<tr>
<td>T3: 2698 h per year</td>
<td>110</td>
<td>11848</td>
</tr>
<tr>
<td>P for trend</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Temperature (daily mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1: 12.5 °C</td>
<td>65</td>
<td>12095</td>
</tr>
<tr>
<td>T2: 13.5 °C</td>
<td>91</td>
<td>15526</td>
</tr>
<tr>
<td>T3: 16.4 °C</td>
<td>113</td>
<td>11344</td>
</tr>
<tr>
<td>P for trend</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1: 409 m³ per year</td>
<td>113</td>
<td>12455</td>
</tr>
<tr>
<td>T2: 721 m³ per year</td>
<td>83</td>
<td>13234</td>
</tr>
<tr>
<td>T3: 1246 m³ per year</td>
<td>73</td>
<td>13276</td>
</tr>
<tr>
<td>P for trend</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

*a: Adjusted for age (years), BMI (kg/m²), physical activity levels (tertiles), smoking (non-smokers, ex-smokers, smokers, missing), unemployment status (no/yes), energy intake (Kcal/d), adherence to the Mediterranean diet (quintiles) and the prevalence of cardiovascular disease (no/yes).
Economic valuation of the mortality benefits of a regulation on SO₂ in 20 European cities

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Background: Since the 1970s, legislation has led to progress in tackling several air pollutants. We quantify the annual monetary benefits resulting from reductions in mortality from the year 2000 onwards following the implementation of three European Commission regulations to reduce the sulphur content in liquid fuels for vehicles.

Methods: We first compute premature deaths attributable to these implementations for 20 European cities in the Aphekom project by using a two-stage health impact assessment method. We then justify our choice to only consider mortality effects as short-term effects. We rely on European studies when selecting the central value of a life-year estimate (€2005 86,600) used to compute the monetary benefits for each of the cities. We also conduct an independent sensitivity analysis as well as an integrated uncertainty analysis that simultaneously accounts for uncertainties concerning epidemiology and economic valuation.

Results: The implementation of these regulations is estimated to have postponed 2212 (95% confidence interval: 772–3663) deaths per year attributable to reductions in sulphur dioxide for the 20 European cities, from the year 2000 onwards. We obtained annual mortality benefits related to the implementation of the European regulation on sulphur dioxide of €2005 191.6 million (95% confidence interval: €2005 66.9–€2005 317.2). Conclusion: Our approach is conservative in restricting to mortality effects and to short-term benefits only, thus only providing the lower-bound estimate. Our findings underline the health and monetary benefits to be obtained from implementing effective European policies on air pollution and ensuring compliance with them over time.