Atmospheric Environment 187 (2018) 107–116

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Short-term effect of tropospheric ozone on daily mortality in Spain

Julio Díaz[a,*], Cristina Ortiz[a], Isabel Falcón[b], Coral Salvador[c], Cristina Linares[a]

[a] Department of Epidemiology and Biostatistics. National School of Public Health, Carlos III National Institute of Health (Instituto Salud Carlos III/ISCIII), Madrid, Spain
[b] Hospital Universitario Nuestra Señora de Candelaria, Santa Cruz de Tenerife, Spain
[c] EPhysLab, Facultade de Ciencias, Universidade de Vigo, Ourense, Spain

ARTICLE INFO

Keywords:
Ozone
Daily mortality
Threshold
Air pollution
Respiratory causes
Circulatory causes

ABSTRACT

Background: Studies that seek to link the impact of ozone with mortality display a number of uncertainties. This study sought to ascertain the functional relationship between ozone and mortality, and analyse its short-term impact on daily natural-, respiratory- and circulatory-cause mortality in Spain.

Methods: We analysed data on daily natural- (ICD 10: A00-R99), respiratory- (ICD 10: J00-J99) and circulatory-cause mortality (ICD 10: I00-I99) for each of Spain's 52 provinces across the period 2000–2009. We calculated the impact of ozone on mortality by reference to relative risks (RRs) using generalised linear models, and performed an overall meta-analysis. Attributable mortality was calculated on the basis of RRs.

Results: A quadratic relationship was observed and the existence of a threshold value identified in 33 of the 46 monitoring stations judged to be valid for ozone data, this threshold value was located above the 80th percentile. The overall RRs for 10 μg/m^3 increases in concentrations of the O_3 threshold value were as follows: 1.033 (95%CI: 1.023–1.044) for natural causes; 1.089 (95%CI: 1.058–1.120) for respiratory causes; and 1.025 (95%CI: 1.018–1.033) for mortality circulatory causes. The annual total of natural-cause ozone-attributable deaths was 499 (95%CI: 277–717), 126 of which (95%CI: 54–194) were due to respiratory causes and 167 (95%CI: 39–293) to circulatory causes.

Conclusions: High ozone concentrations display a quadratic relationship with daily mortality. While this effect is more pronounced in respiratory causes, there is also a short-term effect on natural- and circulatory-cause mortality.

1. Introduction

It is known that tropospheric ozone is a secondary pollutant formed as a result of photochemical reactions involving its precursors, principally nitrogen oxides, volatile non-methane volatile organic compounds, methane, and carbon monoxide (Querol et al., 2012), and that its concentration increases during the hours of greatest solar intensity. In Europe, 96%–98% of the population is exposed to ozone levels in excess of the World Health Organisation (WHO) guideline value (EEA, 2016).

The WHO Air Quality Guidelines Global Update 2005 found support for only a short-term effect of ozone on mortality. Subsequently, the Air Pollution and Health: a Combined European and North American Approach (APHENA) gathered information from studies undertaken in 12 cities across Canada, 90 cities in the USA and 32 cities in Europe, obtaining an association that related ozone concentrations to short-term mortality, due both to all causes and to respiratory and circulatory causes (Katsouyanni et al., 2009). In general, the evidence of associations between ozone and respiratory diseases is robust, but in light of studies conducted to date the evidence of such an association in the case of cardiovascular diseases is still weak (WHO, 2013). Recently however, short-term exposure to daily concentrations of ozone at peak hourly or mean 8-h values has been reported to have adverse effects on all-cause, cardiovascular and respiratory mortality in Europe (Turner et al., 2016).

In studies on long-term exposure to ozone, evidence from the American Cancer Society (Jerrett et al., 2009) indicated an effect on respiratory and, less conclusively, on cardiorespiratory mortality. More recently, cohort studies have reported an effect on mortality among people with potentially predisposing conditions (chronic obstructive disease, diabetes, etc.), and epidemiological and experimental data, based on both human beings and animal models, suggest an effect of ozone exposure on cognitive development and reproductive health, including preterm birth (WHO, 2013). Furthermore, adverse effects on asthma incidence (Lin et al., 2008), asthma severity (Rage et al., 2009), lung function growth (Bae et al., 2015), and higher lung cancer

* Corresponding author. Escuela Nacional de Sanidad, Instituto de Salud Carlos III, Avda. Monforte de Lemos 5, 28029 Madrid, Spain.
E-mail address: j.diaz@isciii.es (J. Díaz).

https://doi.org/10.1016/j.atmosenv.2018.05.059
Received 16 April 2018; Received in revised form 22 May 2018; Accepted 26 May 2018
Available online 30 May 2018
1352-2310/

mortality have also been reported (Fischer et al., 2015).

The Air Pollution and Health: a European Approach (APHEA) was the first study to analyse the short-term effects of air pollution in 15 European cities, four of which were in Spain (Katsouyanni et al., 1995). Additionally, the Spanish Multicentre Study on the Relationship between Air Pollution and Mortality (*Estudio Multicéntrico Español sobre la Relación entre la Contaminación Atmosférica y la Mortalidad/EMECAM*) analysed data on 14 Spanish cities relating to atmospheric concentrations of black smoke, SO_2, NO_2, CO, O_3 and temperature, and observed an association between the above pollutants and short-term mortality in the country's urban population (Ballester et al., 2003). This association was specifically between NO_2 and cardiovascular and all-cause mortality, and between O_3 and cardiovascular mortality, though in this respect the study included data on only 7 and 3 cities respectively (Saez et al., 2002). Lastly, studies conducted on the city of Madrid have reported an association between daily mean ozone concentrations and natural-, circulatory- and respiratory-cause mortality (Díaz et al., 1999; Maté et al., 2010; Guaita et al., 2011).

A recent study (Malley et al., 2017), using updated dose-response functions, has established that ozone-related mortality accounts for 1.04–1.23 million deaths due to respiratory causes worldwide. This is a figure considerably higher than that previously estimated when using the dose-response function derived from prospective data yielded by the Cancer Prevention Study II (Jerrett et al., 2009), which estimated such mortality at around 0.15 to 0.49 million deaths per year (Silva et al., 2013, 2016). It thus evident that a suitable choice of dose-response function and appropriate determination of population exposure levels are both crucial when it comes to quantifying ozone's impact on health. In the case of ozone, another key factor also intervenes, i.e., whether or not there is a threshold above which concentrations are deemed to have an effect on health.

Aspects such as extrapolation of dose-response functions, the precise way in which ozone levels are determined (based on modelling data obtained by satellite or on values recorded by monitors), and setting a single percentile for determination of the ozone threshold level, involve a series of biases, which means in turn that any results obtained can only amount to an approximation of the real effect exerted by ozone on mortality.

This study sought to calculate the impact of daily mean ozone concentrations on mortality due to different specific causes, using dose-response functions calculated for each Spanish province, with ozone concentrations measured in each specific area and ozone-related mortality threshold levels determined for each city, while controlling for the possible effect of other related variables, such as the effect of primary pollutants and even high temperatures. The characteristics of our study mean that it is practically the only one conducted for the entire country based on the above premises of geographical specificity, with the result that our analysis of ozone-attributable mortality assumes special relevance, since Spain is the single most ozone-polluted country in Europe (EEA, 2014).

2. Material and methods

2.1. Variables used in the analysis

2.1.1. Dependent variable

The dependent variable comprised daily natural-cause mortality (ICD 10: A00-R99), daily circulatory-cause mortality (ICD 10: I00-I99), and daily respiratory-cause mortality (ICD 10: J00-J99). These mortality data refer to daily province-wide mortality for each of Spain's 52 provinces across the period 2000–2009, with the exception of Madrid, where the data corresponded solely to the Madrid metropolitan area. All data were supplied by the National Statistics Institute (*Instituto Nacional de Estadística/INE*).

2.1.2. Independent variable

The main independent variable was daily mean O_3 concentrations ($\mu g/m^3$) recorded at monitoring stations situated in each provincial capital, across the period 2000–2009. These data were furnished by the Ministry of Agriculture & Fisheries, Food and Environment (*Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente/MAPAMA*).

2.1.3. Control variables

- Other pollutants: We controlled for the effect of other primary pollutants measured at the same stations at which O_3 was monitored, and took daily mean PM_{10} and NO_{2v} concentrations ($\mu g/m^3$) into account.
- Meteorological variables: Account was likewise taken of the maximum temperatures (Tmax) recorded at the reference observatories situated in the respective provincial capitals. These data were supplied by the State Meteorological Agency (*Agencia Estatal de Meteorología/AEMET*).
- Other control variables: We also controlled for annual (365-day), six-monthly (180-day), four-monthly (120-day) and quarterly (90-day) seasonalities using the sine and cosine functions corresponding to these periodicities.

The trend of the series was introduced by using a count $n_1 = 1$ for day 01/01/2000, $n_1 = 2$ for 02/01/2000, and so on successively for all the series.

Day of the week was controlled for by introducing “dummy” variables for each day; and the autoregressive nature of the dependent variable was similarly controlled for.

2.2. Transformation of variables

2.2.1. Lagged variables or lags

The effect of air pollution on short-term daily mortality may not be immediate. Instead, this effect may be lagged for up to 5 days in the case of PM_{10} and NO_2 (Díaz et al., 1999; Maté et al., 2010) and up to 9 days in the case of O_3 concentrations (Díaz et al., 1999). In the case of heat, the effect of maximum daily temperature on mortality may be lagged for up to 5 days (Alberdi et al., 1998; Díaz et al., 2015). Lagged variables (lags) were therefore constructed for each of the above variables.

2.2.2. Parameterisation of non-linear variables

2.2.2.1. Temperature. > Various studies (Díaz et al., 1999; O'Neill et al., 2003; Stafoggia et al., 2008; Madrigano et al., 2015) indicate that temperature can modify associations between pollution and mortality. This is especially relevant in the case of ozone concentrations, where maximum concentrations tend to occur with high temperatures (Millán, 2009; Díaz et al., 2015).

Temperature registers a U-shaped relationship with mortality, with the effect of cold seen in the left-hand branch and the effect of heat in the right-hand branch (Alberdi et al., 1998). This variable was parameterised on the basis of maximum daily temperature (Tmax) for inclusion in the models, as follows:

Effect of heat (T_{heat}):

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

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

Determination of $T_{threshold}$ had been calculated for each Spanish provincial capital in previous studies which analysed and quantified the behaviour of heat waves vis-à-vis mortality (Díaz et al., 2015).

2.2.2.2. Ozone. A number of studies targeting mortality due to natural (Díaz et al., 1999), circulatory (Maté et al., 2010) and respiratory