Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Seasonal and temperature modifications of the association between fine particulate air pollution and cardiovascular hospitalization in New York state

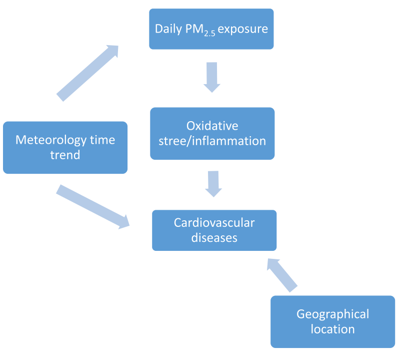
Wan-Hsiang Hsu [a,*], Syni-An Hwang [a,b], Patrick L. Kinney [d], Shao Lin [c]

[a] New York State Department of Health, Bureau of Environmental & Occupational Epidemiology, Albany, NY, United States
[b] University at Albany, Department of Epidemiology & Biostatistics, Rensselaer, NY, United States
[c] University at Albany, Department of Environmental Health, Rensselaer, NY, United States
[d] Columbia University, Mailman School of Public Health, New York, NY, United States

HIGHLIGHTS

- The short-term $PM_{2.5}$ effect on CVDs is identified, with its seasonal pattern and modification by temperature.
- NYC, Long Island & Hudson has year-round $PM_{2.5}$ effect on CVDs.
- The strongest $PM_{2.5}$ effect on CVDs exists in winter and at low temperature days.
- Importance of their joint effect is shown and also provides insight into the health impact from a public health perspective.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form 1 November 2016
Accepted 1 November 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
CVD
$PM_{2.5}$
Temperature
Season
Modification

ABSTRACT

It is known that extreme temperature and ambient air pollution are each independently associated with human health outcomes. However, findings from the few studies that have examined modified effects by seasons and the interaction between air pollution and temperature on health endpoints are inconsistent. This study examines the effects of short-term $PM_{2.5}$ (particulate matter less than or equal to 2.5 μm in aerodynamic diameter) on hospitalization for cardiovascular diseases (CVDs), its modifications by season and temperature, and whether these effects are heterogeneous across different regions in New York State (NYS). We used daily average temperature and $PM_{2.5}$ concentrations as exposure indicators and performed a time series analysis with a quasi-Poisson model, controlling for possible confounders, such as time-relevant variables and dew point, for CVDs in NYS, 1991–2006. Stratification parametric models were applied to evaluate the modifying effects by seasons and temperature. Across the whole year, a 10-μg/m^3 increment in $PM_{2.5}$ concentration accounted for a 1.37% increase in CVDs (95% confidence interval (CI): 0.90%, 1.84%) in New York City, Long Island & Hudson. The $PM_{2.5}$ effect was strongest in winter, with an additional 2.06% (95% CI: 1.33%, 2.80%) increase in CVDs observed per 10-μg/m^3 increment in $PM_{2.5}$. Temperature modified the $PM_{2.5}$ effects on CVDs, and these modifications by temperature on $PM_{2.5}$ effects on CVDs were found at low temperature days. These associations were heterogeneous across four

---

Abbreviations: CI, confidence interval; CVDs, cardiovascular diseases; NYS, New York State; NYC, New York City; PM, particulate matter.

* Corresponding author at: New York State Department of Health, Bureau of Environmental & Occupational Epidemiology, Empire State Plaza, Corning Tower, Room 1203, Albany, NY 12237, United States.

E-mail address: wan-hsiang.hsu@health.ny.gov (W.-H. Hsu).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.008

Please cite this article as: Hsu, W.-H., et al., Seasonal and temperature modifications of the association between fine particulate air pollution and cardiovascular hospitalizatio..., Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.008

$PM_{2.5}$ concentration regions. $PM_{2.5}$ was positively associated with CVD hospitalizations. The short-term $PM_{2.5}$ effect varied with season and temperature levels, and stronger effects were observed in winter and at low temperature days.

1. Introduction

The short-term association between airborne particles and adverse health effects has been documented, with evidence suggesting substantial increased risk of mortality, hospitalization, and emergency department visits (Lin et al., 2012;US EPA, 2004). Temperature can also affect health, and it is well established that extremely high temperatures contribute to increases in mortality and some morbidity, such that a U-, V-, or J-shaped relationship between temperature and health endpoints is usually found (Curriero et al., 2002; Hajat et al., 2006; Kovats et al., 2004). The weather condition is a major driving force of air pollution concentration (Jacob and Winner, 2009; Kinney, 2008; Tai et al., 2010). For example, higher temperature speeds up chemical reactions in the air; lower temperature makes the particulate matter (PM) dissipate in the air more slowly than usual; and rain washes out water-soluble pollutants and PM. Additionally, temperature is associated with season and PM concentration varies with region and season (Bell et al., 2008). $PM_{2.5}$ (PM less than or equal to 2.5 μm in aerodynamic diameter) has been observed to be greatest in winter in some locations. Fares (2013) found that $PM_{2.5}$ increased up to 57% in winter in China and the concentration of $PM_{2.5}$ and PM_{10} (PM less than or equal to 10 μm in aerodynamic diameter) in Turkey was higher in winter than in summer. However, air pollution was also found to be worse during a heatwave in a few studies. These studies describe associations of air pollution with temperature, but the results are not consistent.

Few epidemiological studies have looked at the interaction between PM and temperature and the effect of seasonality, especially on $PM_{2.5}$, and these few studies have produced conflicting results. Bell et al. (2008) reported seasonal variation in the association between $PM_{2.5}$ and cardiovascular hospitalization with the strongest estimated association in winter. However, Katsouyanni et al. (1993) found an interaction effect between high levels of particulate air pollution and high temperature on mortality. Roberts (2004) and Ren et al. (2006) suggested that it is important to consider the possibility of an interaction between daily particular air pollution and daily mean temperature on mortality. Additionally, Samet et al. (1998) and Hales et al. (2000) found little evidence that weather conditions modified the effect of air pollution on mortality. As the prior results are inconsistent and there is an association of air pollution with temperature, the question of whether temperature modifies the effect of $PM_{2.5}$ on cardiovascular diseases (CVDs) remains to be addressed.

The purpose of this study was: (1) to identify the potential health impact of $PM_{2.5}$ on CVD hospitalizations in New York State (NYS) during the period 1991–2006, while controlling for time-relevant confounding variables; (2) to investigate the seasonality of the potential health impact of $PM_{2.5}$; (3) to evaluate a possible modification by temperature of the effect of $PM_{2.5}$; and (4) to examine whether the above-mentioned effects differ across regions.

2. Materials and methods

2.1. Morbidity data

The target population included all NYS residents with hospital admissions due to CVDs during 1991–2006. A CVD case was defined according to a principal diagnosis with the following International Classification of Disease, 9th Revision, including chronic rheumatic heart disease (ICD-9 codes 393–396), hypertension (401–405), ischemic heart diseases (410–414), cardiac dysrhythmias (427), heart failure (428), and cerebrovascular diseases (430–434, 436–438). Discharge data for hospital admissions due to CVDs among residents of NYS from 1991 to 2006 were obtained from the NYS Department of Health's Statewide Planning and Research Cooperative System. This is a legislatively mandated database that contains hospital discharge data for at least 95% of all acute care hospital admissions in NYS, excluding admissions to psychiatric and federal hospitals. The data included principal diagnoses, hospital admission date, sources of payment, date of birth, sex, race, ethnicity, and street address. About 94% of residential addresses were geocoded to street level, and 5% to zip code level. <1% of the addresses could not geocoded.

2.2. $PM_{2.5}$ concentration and weather data

Fourteen weather regions in NYS that were created so that temperature within each region was relatively homogeneous are shown in Fig. 1 (Chinery and Walker, 2009). Each weather region was assigned a daily average value of temperature and dew point based on hourly meteorologic observations obtained from the National Center for Atmospheric Research (2009) for 18 first-order airport weather stations maintained by the National Weather Service or the Federal Aviation Administration. Daily 24-hour average $PM_{2.5}$ concentration was estimated using all monitoring observations and modeled data for those with missing values as described by Hogrefe et al. (2009).

2.3. Statistical analysis

We conducted time-series analyses to characterize the short-term effect of $PM_{2.5}$ with CVDs and modify it by season and temperature strata using a quasi-Poisson model, while controlling for possible confounders. We first built the basic model without air pollution, with the following choices regarding the control of confounders:

$$\begin{aligned}\log E[Y_t] &= DOW_t + PUB_t + BOUT_t + ns(temp_t, DF = 6)\\ &+ ns\left(temp_{t,1-3,}\ DF = 6\right) + ns(dewp_t, DF = 3)\\ &+ ns\left(dewp_{t,1-3,} DF = 3\right) + ns(t, DF = 7/year),\end{aligned}$$

where Y_t is the number of CVDs on day t; DOW_t, PUB_t, and $BOUT_t$ are day of week, public holidays, blackout events (8/14/2003 and 8/15/2003); $temp_t$ is the average temperature on day t and $temp_{t,1-3}$ is a moving average of temperature for the previous three days; $dewp_t$ and $dewp_{t,1-3}$ are current day and 3-day moving average of dew point; ns(·, DF) indicates a natural spline with degrees of freedom (DF). The DF numbers used are within the range used in other studies (Cheng and Kan, 2012; Roberts, 2004).

Before examining the results modified by season and temperature, we assessed the short-term effects of $PM_{2.5}$ on the same day (lag 0) and 1, 2, and 3 days before (lag 1–lag 3) on CVDs in 14 NYS weather regions. For this *main model*, we introduced a linear parametric term of $PM_{2.5}$ concentration into the basic model. We also performed this *main* analyses for the five major cause-specific CVD hospitalizations. To examine the season-specific $PM_{2.5}$ effects on CVDs, we extended the *main model* by replacing a linear parametric term of $PM_{2.5}$ concentration with an interaction term between $PM_{2.5}$ and seasons. The four

Please cite this article as: Hsu, W.-H., et al., Seasonal and temperature modifications of the association between fine particulate air pollution and cardiovascular hospitalizatio..., Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.11.008