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Temperature as a modifier of the effects of fine particulate matter on acute mortality in Hong Kong

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ABSTRACT

Interactions between particulate matter with aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$) and temperature on mortality have not been well studied, and results are difficult to synthesize. We aimed to assess modification of temperature on the association between $PM_{2.5}$ and cause-specific mortality by stratifying temperature into low, medium, and high stratum in Hong Kong, using data from 1999 to 2011. The mortality effects of $PM_{2.5}$ were stronger in low temperature stratum than those in high. The excess risk (%) per 10 μg/m^3 increase in $PM_{2.5}$ at lag 0–1 in low temperature stratum were 0.94% (95% confidence interval: 0.65, 1.24) for all natural, 0.88% (0.38, 1.37) for cardiovascular, and 1.15% (0.51, 1.79) for respiratory mortality. We found statistically significant interaction of $PM_{2.5}$ and temperature between low and high temperature stratum for all natural mortality. Our results suggested that temperature might modify mortality effects of $PM_{2.5}$ in Hong Kong.

1. Introduction

Numerous epidemiological studies around the world have found short-term associations between exposure to ambient particulate matter (PM) and mortality (Ostro et al., 2008; Pope III et al., 2002; Wong et al., 2002a). These findings are consistent with many multicity studies conducted in western (Katsouyanni et al., 1997; Samet et al., 2000) and eastern countries (Chen et al., 2013; Wong et al., 2008b). Recently, research interest has been focused on the potential role of modifiers for ambient PM on adverse health outcomes. Some studies investigated the modification of meteorological conditions on PM-associated mortality such as season (Kan et al., 2008; Peng et al., 2005; Wong et al., 2002a), demographic characteristics such as sex (Cakmak et al., 2006), socioeconomic status (SES) (O'Neill et al., 2003; Wong et al., 2008a), and pre-existing health status such as chronic obstructive pulmonary disease (COPD) (Bateson and Schwartz, 2004). Exploring potential modifiers of PM effects can aid to understand the underlying mechanism of PM triggered diseases, benefit risk assessment (Bellinger, 2000), and direct public policy making.

Temperature is an important modifier for PM, which has a great impact on mortality. Multicity studies have provided clear and convincing evidence that exposure to both hot and cold temperature was associated with increased risks of morbidity and mortality (Curriero et al., 2002; Ma et al., 2014). The independent effect of temperature on mortality has been extensively reported (Anderson and Bell, 2009; Xu et al., 2013; Zhou et al., 2014), but only a few studies have examined the effects of temperature modification on PM-associated mortality. Most of these studies identified significant interaction between PM and temperature ($P<0.05$), with stronger health effects of PM in high temperature days for all natural (Qian et al., 2008; Ren and Tong, 2006), and cardiovascular mortality (Li et al., 2011). Cheng and Kan (2012) found significant interaction ($P<0.05$) with higher PM effects in low temperature days (<15th temperature percentile) for all natural and respiratory mortality. However, one multicity study conducted in Italy (Stafoggia et al., 2008) reported non-significant interaction ($P>0.05$). Therefore, the findings of PM-temperature interaction on mortality are not consistent.

In Hong Kong, air quality is deteriorating with pollutant levels and the associated health hazards are similar to or even greater than those in other developing cities in South Asia (Wong et al., 2008b, 2002b). In addition, in contrast to multicity studies which reported stronger health effects of PM_{10} in warm seasons (Spring and Summer) than those in cool seasons (Autumn and Winter)

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Nomenclature

$PM_{2.5}$	Particulate matter with aerodynamic diameter less than or equal to 2.5 μm
PM_{10}	Particulate matter with aerodynamic diameter less than or equal to 10 μm
NO_2	Nitrogen dioxide
SO_2	Sulfur dioxide
O_3	Ozone
TMR	Temperature–mortality relationship
SEC	Socioeconomic status
COPD	Chronic obstructive pulmonary disease
ICD-9	Ninth revision of the international classification of diseases
ICD-10	Tenth revision of the international classification of diseases
CVD	Cardiovascular Disease
RD	Respiratory Disease
dow	Days of the week
WHO	World Health Organization
CI	Confidence interval
GAM	Generalized additive model
ER	Excess risk
dfs	Degrees of freedom
ns	Natural spline
OC	Organic carbon
EC	Elemental carbon

(Peng et al., 2005; Stieb et al., 2002), a study in Hong Kong showed higher health effects in cool seasons (October to March) than those in warm seasons (April to September) (Wong et al., 2002a). Season may be a good proxy for temperature, but it is not a reliable indicator to classify low and high temperature days. Owing to the increasing of global warming and urbanization, it may induce misclassification.

Thus far no study has assessed the interaction between PM and temperature in Hong Kong for cause-specific mortality. So we aimed to evaluate the effect modification of temperature on mortality effects of fine particulate matter ($PM_{2.5}$). We first identified temperature cut-offs based on temperature–mortality relationships (TMRs) for cause-specific mortality to classify temperature into low, medium and high three strata, and then determined the extent to which the effects of $PM_{2.5}$ on mortality were modified by these temperature strata.

2. Materials and methods

2.1. Mortality data

Daily mortality data from 1999 to 2011 were collected from the Hong Kong Census and Statistics Department. Cause-specific mortality was coded according to the International Classification of Diseases (ICD) by the Department of Health, 9th revision (ICD-9) before 2001 and 10th revision (ICD-10) from 2001. In our study, mortality for all natural cause was coded as ICD-9:1-799 or ICD-10:A00-R99; cardiovascular disease (CVD) as ICD-9:390-459 or ICD-10:I00–I99; respiratory disease (RD) as ICD-9: 460–519 or ICD-10: J00-J99. The agreement between these two mortality ICD coding systems was over 90% in Hong Kong (Hong Kong Department of Health, 2005).

2.2. Pollutant and meteorological data

Daily 24-hr average concentration of air pollutants, including particulate matter with aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$), particulate matter with aerodynamic diameter less than or equal to 10 μm (PM_{10}), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), and daily 8-hr (10:00–18:00hr) average concentration of ozone (O_3) were collected by the Environmental Protection Department of Hong Kong from ten general monitoring stations, including Central and Western, Eastern, Kwai Chung, Kwun Tong, Sha Tin, Sham Shui Po, Tai Po, Tung Chung, Tsuen Wan, and Yuen Long. The ten monitoring stations are all general stations situated at an average of 20 m above ground level. Data were regarded as missing if numbers of hourly concentration for one particular day were less than 75% (18-hr for $PM_{2.5}$, PM_{10}, NO_2, SO_2, and 6-hr for O_3). For meteorological data, we extracted daily mean temperature in Celsius and relative humidity in percentage from the Hong Kong Observatory.

2.3. Statistical methods and data analysis

2.3.1. Identifying temperature cut-offs

Two main steps were adopted in sequence to identify temperature cut-offs.

Step 1: identifying the best lag day of temperature

First, we built a core model for cause-specific mortality using quasi-Poisson generalized additive modeling (GAM). In the core model, we included dummy variable for the day of the week (dow), a natural smoothing spline for time trend and relative humidity with four degrees of freedom, and daily admission numbers of hospitalization due to influenza. The core model is shown as follows:

$$log[E(Y_t|X)] = \mu + ns(time, df) + ns(relative\ \ humidity_t, df = 4) + dow_t + Influenza_t, \quad t = 1, \ldots n, \tag{1}$$

where t refers to the day of study; $E(Y_t|X)$ denotes expected daily death on day t; μ is the mean number of deaths; $ns(\bullet)$ denotes natural smoothing spline function; df denotes degree of freedom; dow denotes day of the week; $Influenza$ denotes daily admission numbers of hospitalization due to influenza; n denotes number of days.

We used the partial autocorrelation function (PACF) to guide the selection of degrees of freedom (dfs). Specifically, we used 3 to 10 dfs per year for time trend for each disease category (all natural, cardiovascular, and respiratory mortality). We regarded time trend was adequately controlled for if the absolute values of PACF coefficients were <0.1 for the first 2 lag days and no systematic patterns in the PACF plots were observed (Wong et al., 2008a). The PACF plots are shown in Supplementary Material.

Following selection of dfs for time trend for each disease category, we selected the best lag day to identify cool and warm temperature cut-offs. We adopted similar approach to a previous study of our group (Xu et al., 2013). Temperatures with log relative risk equal to zero in temperature–mortality relationship (TMR) would be selected as cut-offs. We used the average temperature of current and previous day (lag 0–1) to identify warm temperature cut-off. After including a smoothing temperature term with different lag days by natural spline function with four dfs in the core model, we selected the best lag day for cool temperature cut-off using the