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Temperature and Daily Mortality in Shanghai: A Time-series Study

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Objective To investigate the association between temperature and daily mortality in Shanghai from June 1, 2000 to December 31, 2001. **Methods** Time-series approach was used to estimate the effect of temperature on daily total and cause-specific mortality. We fitted generalized additive Poisson regression using non-parametric smooth functions to control for long-term time trend, season and other variables. We also controlled for day of the week. **Results** A gently sloping V-like relationship between total mortality and temperature was found, with an optimum temperature (e.g. temperature with lowest mortality risk) value of 26.7°C in Shanghai. For temperatures above the optimum value, total mortality increased by 0.73% for each degree Celsius increase; while for temperature below the optimum value, total mortality decreased by 1.21% for each degree Celsius increase. **Conclusions** Our findings indicate that temperature has an effect on daily mortality in Shanghai, and the time-series approach is a useful tool for studying the temperature-mortality association.

Key words: Temperature; Mortality; Time-series

INTRODUCTION

Weather could modulate human health. It has been known for a long time that there is an association between episodes of extremely hot or cold temperature and mortality[1]. These studies showed that mortality tended to rise with increasingly hot or cold temperatures from an optimum temperature value. Global warming and other climate phenomena, such as El Niño, have sparked new interest in the weather-mortality relation.

Although it has long been known that hot or cold temperatures are associated with increases in mortality, much work in this field was based on isolated episodes ("heat or cold waves")[2,3], and was criticized on the grounds of an uncertain baseline and on the overestimates that could be produced from short-term mortality displacement[4]. In contrast, a time-series approach using daily data could overcome some of these problems[5-7].

In the present study, contemporary method of time-series analyses was used to study the relationship between temperature and mortality in Shanghai from June 1, 2000 to December 31, 2001. It was expected to explore the short-term effect of temperature on total and

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cause-specific mortalities, and to find whether there exists an optimum temperature with relation to the increase of mortality in Shanghai.

METHODS

Data

Daily weather, air pollution and mortality data in the urban districts of Shanghai from June 1, 2000 to December 31, 2001 were collected. The mortality data were provided by Shanghai Center of Disease Control and Prevention. These mortality data excluded persons whose deaths were attributed to accidental causes. Information was collected on underlying cause of death, coded according to the International Classification of Diseases, Ninth Revision, to classify deaths as due to cardiovascular disease (codes 390-448), respiratory disease (codes 460-519), and all other diseases.

Weather data were used as potential predictors for modeling mortality. The weather data were provided by Shanghai Meteorological Bureau. These data included daily average temperature, dew point, and relative humidity. Considering ambient air pollution was proved to be associated with daily mortality change, we also collected daily air pollutants concentrations during the period. Air pollution data (daily average PM_{10}, SO_2 and NO_2 concentrations) were retrieved from the database of Shanghai Environmental Monitoring Center.

Statistical Models

Counts of daily death were modeled in a Poisson regression. In a standard Poisson regression[8], log mortality is assumed to be a linear function of temperature and other predictors (dew points, relative humidity, air pollutant concentrations). In this study, we assumed that log mortality was a smooth but not necessarily linear function. We estimated this smooth function by using a generalized additive model (GAM)[9], which fits a cubic spline function of temperature and other variables. Instead of summarizing the temperature-mortality association with a single relative risk value for all temperatures, we could obtain a relative risk estimate that was a smoothly changing function of temperature using GAM. In exploring the predictor-mortality relation, we began with lagged predictor variables to allow for possible delayed effects of each predictor, starting with variables unlagged and lagged by 1-5 days. Considering that the regression of mortality on predictors might also be affected by key potential effect modifiers, such as longer-term changes in population characteristics, health behaviors, trends in medical practices or access to health care, and potential seasonal-related confounders, we adjusted these variables by including a smooth function of calendar time as a predictor in our analysis. We also controlled for day of the week as a dummy variable.

The degree of smoothness of the estimated mortality-predictor relative risk curve is controlled by its number of degrees of freedom. For example, a linear function has 1 df for its one slope, and a quadratic curve has 2 df for its slope and curvature. We used Akaike's Information Criterion (AIC), a measure of fit, to select the smoothing parameters[10]. AIC is an estimate of expected prediction error, and the one with lower AIC is preferred.

We also estimated the optimum temperature with minimum mortality-risk in Shanghai and calculated the relative risks at temperatures lower (cold slope) and higher (hot slope) than the temperature. The slope for cooler temperature and for hotter temperature was found by fitting a linear regression line through those points in the fitted relative risk curve from the GAM before and after the turning point, respectively.

All analyses were carried out using S-PLUS 2000 software (Insightful Corp, Seattle, U.S.A). Considering the default settings in the *gam* function of the S-Plus software package do not assure convergence of its iterative estimation procedure and can provide biased estimates of regression coefficients and standard errors[11], we analyzed the data with more stringent convergence parameters than the default settings when using the *gam* function.

RESULTS

Table 1 provides summary of daily total (non-accidental), cardiovascular and respiratory mortality, temperature, dew points, relative humidity, and air pollutants concentration changes for Shanghai from June 1, 2000 to December 31, 2001. A total of 64 862 deaths were included in the analysis. During the period, on average there were 112 deaths per day in the total population in the study area, and approximately 39 persons died from cardiovascular diseases, and 11 persons from respiratory diseases.

TABLE 1

Summary Statistics of Mortality Outcomes, Meteorologic Measures and Air Pollution Levels in Shanghai (June 1, 2000-December 31, 2001)

	No (day)	$\bar{x}$	SD	Min	P(25)	Median	P(75)	Max
Mortality Counts								
Total	579	112.02	21.08	64	84	108	139	183
Cardiovascular Diseases	579	39.09	9.97	19	25	37	52	72
Respiratory Diseases	579	10.71	5.19	0	4	10	17	31
Meteorologic Measures								
Temperature (℃)	579	19.0	8.4	-1.75	4.2	20.8	29	32.8
Relative Humility (%)	579	74.9	10.4	39.8	55.5	75.5	87.5	97.0
Dew Point (℃)	579	14.1	8.9	-13.8	-2.8	15.6	24.6	26.7
Air Pollutants Concentrations								
PM_{10} (μg/m^3)	579	91.14	51.85	17	35	76	155	385
SO_2 (μg/m^3)	579	42.49	20.17	10	17	39	62	146
NO_2 (μg/m^3)	579	32.46	14.43	10.4	13.6	29.6	46.4	102.8

Fig. 1 is the scatter plot of daily temperature *versus* total, cardiovascular and respiratory mortality. It could be seen that total and cause-specific mortality increase at both low and high temperatures.

After control for mortality long-term change, season, other weather and air pollution variables, Fig. 2 shows the temperature-mortality relative risk curves for total mortality, cardiovascular disease mortality, and respiratory disease mortality at the best lagged-day by using GAM model described above (df = 5). We found that the effect of temperature on mortality varied for different cause of death (Figs.1-3). For total (non-accident) deaths, mortality risk decreased from the lowest temperature, and increased above a turn point (26.7℃), producing a "V" relationship. For the deaths due to cardiovascular and respiratory diseases, the shapes of two curves were similar, both decreasing from the lowest temperature, then extending relatively sharply from a certain temperature.

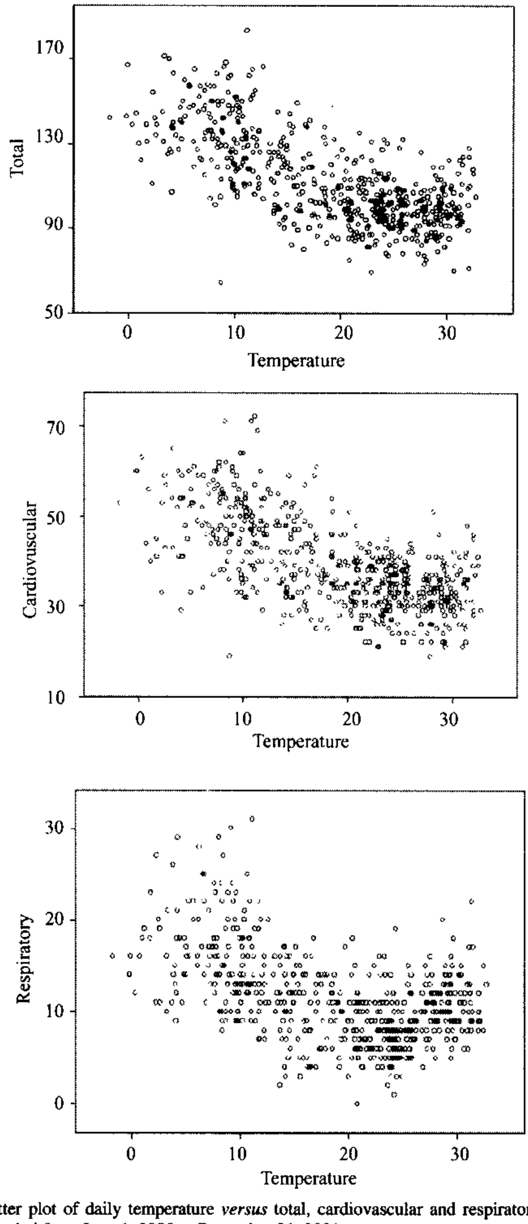

FIG. 1. Scatter plot of daily temperature *versus* total, cardiovascular and respiratory mortality in Shanghai from June 1, 2000 to December 31, 2001.

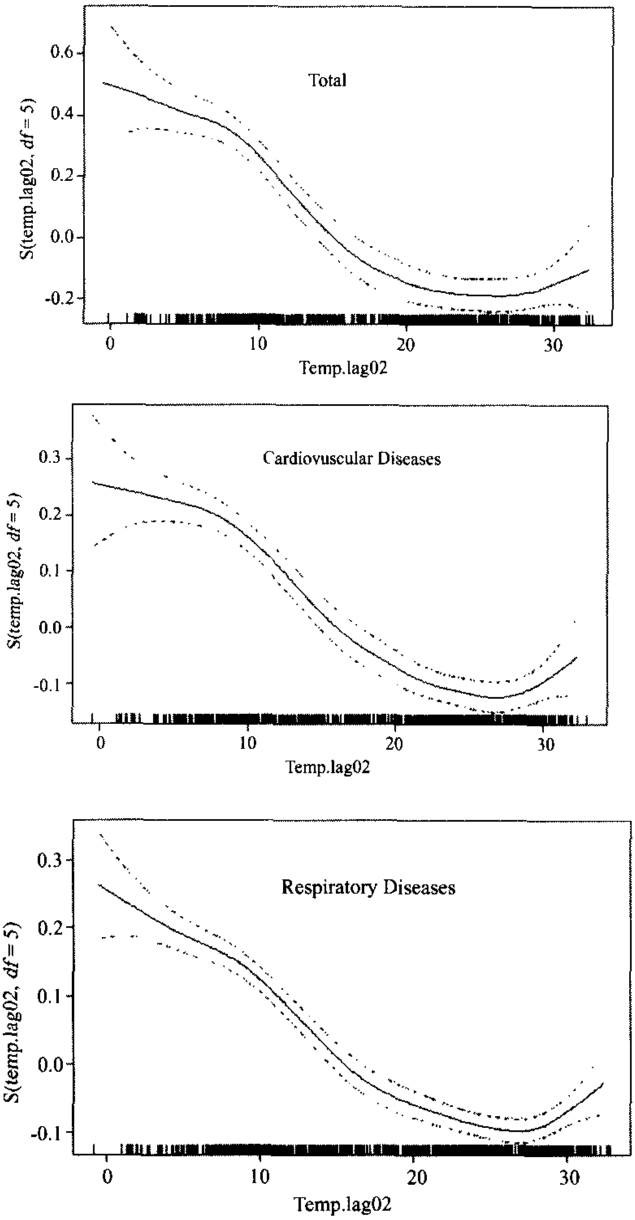

FIG.2. Temperature-total, cardiovascular and respiratory mortality relative risk functions for Shanghai (*df* = 5).

We also estimated the relative risk for total mortality in terms of cold slope and hot slope respectively in Shanghai. For the cold slope (below 26.7℃), an increase of 1℃ of temperature corresponded to 0.73% decrease in total mortality; however, for the hot slope (above 26.7℃), an increase of 1℃ of temperature corresponded to 1.21% increase in total mortality.

DISCUSSION

Temperature has been recognized as a physical agent able to induce health effects. The rapid built-up of greenhouse gases is expected to increase both mean temperature and temperature variability around the world[12]. This will add urgency to the need of better understanding the relationship between temperature and health events.

The results presented in this paper suggest an optimum value of average temperature above or below which point temperature-related deaths occur. This value is estimated to be about 26.7℃ for Shanghai and the relationship between temperature and mortality is in "V" shape. In addition, the effect of temperature on cardiovascular and respiratory mortality was observed. In general, our results were consistent with prior findings.

The approach we used for the analysis, generalized additive models (GAM), can characterize the relation between temperature and mortality in Shanghai flexibly, without making strong prior assumptions about the shape of the relative risk curve. Many of the previous reports used conventional linear regression techniques that would be less appropriate for discrete data and correlated variables. That is one advantage of the time-series approach we used. The types of models that we used are also applicable to estimating weather-related mortality given various future climate scenarios.

The limitations of our analyses should be noted, and substantial additional investigation of this association remains. Compared with other similar studies[6,7], the data we collected are limited in duration time. Our analyses still did not address the "harvesting" effect in association with daily exposure to temperature, which is a major concern on the methodology issue of time-series studies[13]. We did not address in detail how the temperature-mortality association changes by gender, age, and many other factors. Future research should study an aggregate weather variable that incorporates temperature, dew point, and wind speed, etc. Also, other confounders, such as influenza epidemics, should be further controlled. The solution of these problems all requires more detailed health and weather data. In addition, investigation of the effects of air-conditioning and heating on the association between weather and mortality should be conducted in Shanghai considering the wide use of these facilities.

When the data were stratified by cause of death, we found the same relation for cardiovascular and respiratory mortality. Also, greater effects of temperature, especially high temperature, on cardio-respiratory deaths were observed in the current study. Recently, mechanisms of the effects of temperature on mortality, especially cardiovascular diseases, have been postulated. For example, blood pressure and fibrinogen levels have been found to increase during winter[14]. Also, heat wave can increase demand on the cardiovascular system required for physical cooling[15].

In summary, our findings support prior association between temperature and acute mortality change. From our analyses, it is suggested that public health programs should be implemented to prevent heat and cold-related mortality.

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