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Has the impact of temperature on mortality really decreased over time?

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HIGHLIGHTS

- Time-series analysis was conducted to analyze the association of temperature and mortality.
- Temporal variation on mortality effects varied at different lags.
- Temporal variation on mortality effects depends on both harvesting and lagged effects.

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ABSTRACT

Many studies have reported that the temperature effect on mortality has decreased over time. However, most of those studies did not consider lag times longer than 10 days, which is frequently used to explore its effect net out compensatory effect (harvesting) and lag effects.

We sought to examine the temporal variation of the temperature effect on mortality, considering both a lag effect and mortality displacement.

Time-series analysis was conducted with lag of temperature up to 21 days on all-cause, cardiovascular, cerebrovascular, and respiratory deaths. We applied a series of time-windows, 8 years long, with which we compared the oldest to more recent intervals and took consecutive annual variation, excluding an interannual harvesting effect. At the 99th percentile (29 °C), relative to the 90th percentile (25 °C), we found a decreasing trend of heat effect on concurrent days whereas the risk of cardiovascular deaths increased over time. Cumulative risks of deaths increased recently except for respiratory disease. At the 10th percentile (−1 °C) relative to the 25th percentile (4 °C), cumulative cold effects on cardiovascular and respiratory mortality have emerged recently.

Our study showed differences in the temporal variation in the temperature effect on mortality at concurrent day and in cumulative term. It is suggested that the time-varying nature of the temperature–mortality relationship depends not only on suggested factors, such as improvements in technology and infrastructure, and human physiological acclimatization, but also mortality displacement and lagged effects. Further studies on its complex nature are needed to provide relevant evidence for public health policy making.

1. Introduction

The impact of temperature on human health has been studied worldwide in epidemiological research (Analitis et al., 2008; Braga et al., 2002; Vaneckova et al., 2008). These studies have reported that exposure to heat or cold temperature increases the risk of mortality and morbidity. The effects of heat or cold temperatures are to provoke changes in human physiological systems including changes in blood pressure, increased blood viscosity, and elevated levels in blood cholesterol (Keatinge et al., 1986; Van der Bom et al., 1997). These physiological changes can lead to serious human health impacts.

Recent reports have postulated that the impact of temperature on mortality may change over time (Åström et al., 2013; Carson et al., 2006; Davis et al., 2002, 2003; Guo et al., 2012a; Ha and Kim, 2013; Michelozzi et al., 2006; Morabito et al., 2012; Petkova et al., 2014; Schifano et al., 2012). In fact, it has been reported consistently that there was a systematically declining pattern of the effect of temperature over periodic time. The declining pattern may be related to not only improved technologies or infrastructure, including the use of air conditioners, warning systems of extreme temperatures, better designed urban planning, and enhanced access to medical services, but also, perhaps, human physical acclimatization to temperature changes (Åström et al., 2013; Davis et al., 2002, 2003; Greenberg et al., 1983; Kalkstein et al., 1996; Petkova et al., 2014; Seretakis et al., 1997). Carson et al. (2006) indicated that protective roles of those factors outweighed even the aging population, where larger number of older people may suffer due to extreme temperatures.

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However, two contexts need to be discussed in terms of the temporal variation of an effect of temperature on mortality. First, most of these studies focused on its effect on only a single day and/or with short time lags. Because a lagged effect has been seen in the relationship between temperature and health outcomes (Braga et al., 2002; Carder et al., 2005; Goldberg et al., 2011; Guo et al., 2012b; Yu et al., 2011), longer lag effects need to be considered. Also, in most of these studies, the phenomenon that critically ill people were caused to die earlier than they would otherwise do, so-called "mortality displacement," was not taken into account. A compensatory effect with premature deaths leads to overestimating the true effect of temperature. This overestimation can be more important in studies on time-varying effects if mortality displacement is not consistent over time. Petkova et al. (2014), who considered lag structures up to 10 days, reported decadal changes in cumulative heat effect up to lag 5 as the main results even though the pattern of lagged effects showed a lag of 5 days was not sufficient to capture fully harvesting effect during a certain decade. A recent systematic evaluation revealed that harvesting effect during summer season was remarkable in Korea compared to other 12 countries (Guo et al., 2014). Results in other studies showed that longer lag structures are needed to reflect harvesting effects in Seoul, Korea (Ha et al., 2011b).

Thus, in this study, we sought to analyze temporal variation in the effect of temperature on mortality in Seoul, the capital city of Korea, from 1995 to 2011, contemplating both the lagged effect and mortality displacement.

2. Methods and materials

2.1. Study scope and data

Data on meteorological factors, mortality and air pollution in Seoul for the period of 1995 to 2011 were obtained from Statistics Korea, National Institute of Environmental Research, and Korea Meteorological Administration, respectively. Meteorological factors were temperature and relative humidity which were hourly measured in a station on Jongro district. We averaged temperature and relative humidity on daily basis. Daily mortality was categorized as all-cause death except for extraneous causes (International Classification of Disease, Tenth Revision [ICD-10]: A00–R99 and Ninth Revision [ICD-9]: 1–799), cardiovascular disease (ICD-10: I20–52, ICD-9: 410–429), cerebrovascular disease (ICD-10: I60–I69, ICD-9: 430–438) and respiratory disease (ICD-10: J00–J99, ICD-9: 460–519). Particulate matter with an aerodynamic diameter of <10 μm (PM_{10}) was used to reflect air pollution.

2.2. Modeling approach

We adapted a Poisson regression model with over-dispersion to time-series data to investigate the effect of extreme temperatures on deaths. We constructed a constrained lag structure using a distributed lag non-linear model (DLNM) in a generalized linear model. This structure is called cross-basis because of one basis for lagged term and the other for non-linear term of temperature (Armstrong, 2006). Lagged terms up to 21 days were chosen because previous studies have shown that heat effects tends to be seen within a single day and for cold effect it is likely to last for around 1–2 weeks (Braga et al., 2002; Carder et al., 2005; Goldberg et al., 2011; Guo et al., 2012b, 2014; Yu et al., 2011). A natural cubic spline (NCS) with five degrees of freedom (df) was adapted to constrain lag structure. For estimating the non-linear effect of temperature, a cubic b-spline with six degree of freedom was used (Goldberg et al., 2011). To control for potential confounders, day of the week, holidays, time trends, and humidity were adjusted in the model. Dummy variables were used for day of the week and holidays. Time trends with seasonal effects and humidity were adjusted using NCS with 7 df/year and with 4 df, respectively. A linear term was used to adjust for air pollutant because dose–response curve of airborne particles have been understood to be linear without thresholds (Schwartz and Zanobetti, 2000).

Overall, the model was

$$\begin{aligned}\log[E(Y)] = b_0 &+ \alpha(\text{month}) + \alpha(\text{day of the week}) + \alpha(\text{holiday}) \\ &+ \text{NCS}(\text{humidity}, \text{df} = 4) \\ &+ \text{NCS}(\text{time trend}, \text{df} = 7/\textit{year}) \\ &+ \text{crossbasis}(\text{temperature01–21}, \text{df} = 6) + b_1 PM_{10}.\end{aligned}$$

Time-varying effects of temperature on mortality have been analyzed in several studies, using, arbitrarily, a study period divided into two or three intervals (Carson et al., 2006; Davis et al., 2002, 2003; Ha and Kim, 2013; Michelozzi et al., 2006; Morabito et al., 2012; Schifano et al., 2012). Studies based on data with a period of a century made decadal changes (Åström et al., 2013; Petkova et al., 2014). To our knowledge, only one reported study tried to analyze the year by year variation (Guo et al., 2012a). Instead of using intervals or year by year, we used a time window approach to explore the temporal variation. We arbitrarily used time windows of 8 years long to see consecutive variation and compare intervals; in total, 10 time windows over the 17 years. To test temporal trends over time-windows, we performed east square linear regression of time-windows on each relative risks using a weight of inverse of a standard error for each relative risks. The same approach was adapted in a previous study (Åström et al., 2013).

To address mortality displacement, we applied the principle that a negative association with mortality at longer lags would follow a positive association at a shorter lag if mortality displacement exists (Hajat et al., 2005). If the overall cumulative estimate is smaller than the estimates at single day or after a short lag, then it is interpreted as a compensatory effect offsetting the effect of temperature. Several studies have applied this principle in estimating the impact of temperature considering mortality displacement (Baccini et al., 2008; Guo et al., 2012b; Ha et al., 2011b).

All analyses were conducted using SAS 9.4 and R 3.0.2 software.

3. Results

3.1. Descriptive statistics

Table 1 shows that daily mean temperature was 12.8 °C, on average, and ranged from −15.7 °C to 30.4 °C during the study period. The level of PM_{10} was relatively high and its mean was 62.6 μg/m³. The mean number of daily all-cause deaths was 92.6, with a standard variation of 11.8. For cardiovascular disease, the mean number of daily deaths

Table 1
Distribution of metrological variables, air pollution variable, and deaths from all causes, cardiovascular, cerebrovascular, and respiratory disease, Seoul, 1995–2011.

	Mean	Standard deviation	Percentiles				
			0th	25th	50th	75th	100th
Daily mean temperature (°C)	12.8	10.2	−15.7	4.0	14.3	22.0	30.4
Daily mean humidity (%)	62.0	14.7	18.8	51.2	62.3	72.7	96.3
PM_{10} (μg/m³)	62.6	36.4	5.0	38.6	55.8	78.8	869.1
All-cause deaths							
Total age	92.6	11.8	55	84	92	100	184
≥65 years of age	60.2	10.6	28	53	60	67	103
Cardiovascular deaths							
Total age	08.5	03.1	0	6	8	10	21
≥65 years of age	05.9	02.7	0	4	6	8	17
Cerebrovascular deaths							
Total age	13.8	04.4	1	11	14	17	31
≥65 years of age	10.1	03.5	1	8	10	12	25
Respiratory deaths							
Total age	05.6	02.6	0	4	5	7	21
≥65 years of age	04.6	02.4	0	3	4	6	18