Effects of temperature on mortality in Hong Kong: A time series analysis

Wen Yi[a]* and Albert P.C. Chan[a]

[a] Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

*Corresponding author

Wen Yi

ZN703, Department of Building and Real Estate

The Hong Kong Polytechnic University

11 Yuk Choi Road, Hung Hom, Kowloon

Hong Kong, China

Tel.: (852) 2766 5794; Fax: (852) 2764 5131

E-mail address: yiwen96@163.com

Abstract

Although interest in assessing the impacts of hot temperature and mortality in Hong Kong has increased, less evidence on the effect of cold temperature on mortality is available. We examined both the effects of heat and cold temperatures on daily mortality in Hong Kong for the last decade (2002-2011). A quasi-Poisson model combined with a distributed lag non-linear model was used to assess the non-linear and delayed effects of temperatures on cause-specific and age-specific mortality. Non-linear effects of temperature on mortality were identified. The relative risk of non-accidental mortality associated with cold temperature (11.1°C, 1st percentile of temperature) relative to 19.4°C (25th percentile of temperature) was 1.17 (95% confidence interval (CI): 1.04, 1.29) for lags 0–13. The relative risk of non-accidental mortality associated with high temperature (31.5°C, 99th percentile of temperature) relative to 27.8°C (75th percentile of temperature) was 1.09 (95% CI: 1.03, 1.17) for lags 0–3. In Hong Kong, extreme cold and hot temperatures increased the risk of mortality. The effect of cold lasted longer and greater than that of heat. People older than 75 years were the most vulnerable group to cold temperature, while people aged 65-74 were the most vulnerable group to hot temperature. Our findings may have implications for developing intervention strategies for extreme cold and hot temperatures.

Keyword： Cardiovascular mortality, Distributed lag non-linear model (DLNM), Mortality, Respiratory mortality, Temperature

Introduction

In recent years climate change has led to an increased frequency and intensity of extreme temperatures, in the form of both heat waves and cold spells (Song et al. 2014). Given these increasing periods of extreme temperatures, understanding the effects of prolonged periods of hot and cold temperatures is of particular importance to human health (Anderson and Bell 2009; Gasparrini and Armstrong 2011). High temperatures have garnered considerable attention because of their short-term adverse health impacts. Increased mortality, hospital admissions, and emergency room visits worldwide have been associated with vulnerable populations exposed to heat waves (Semenza et al. 1999; Knowlton et al. 2009; Anderson and Bell 2011). However, several studies reported that the adverse health effects of cold temperatures may be more significant than those of heat temperatures in Spain, Canada, Shanghai, and Taiwan (Lin et al. 2011; Ma et al. 2011; Martin et al. 2012; Wang et al. 2012). Mortality risk associated with low temperatures is likely underestimated when studies fail to address the prolonged effect of low temperature (Mercer 2003; Martin et al. 2012).

Multi-city studies reported the cold effects were most significant in warm regions (Langford and Bentham 1995; Wang et al. 2012) or areas with moderate winter climates (Conlon et al. 2011). Residents in warm regions have less physical, social, and behavioral adaptations to low temperatures. Hong Kong has a subtropical climate, of which the summer (May-September) is hot and humid. There is much concern about the public health threat of elevated temperatures, especially considering the potential impacts of climate change and the increased heat island effects in urban settings (Chau et al. 2009; Chan et al. 2012; Goggins et al. 2012). However, studies focusing on the effect of low temperature on the mortality in Hong Kong remain scarce.

Mortality risk depends not only on exposure to the current day's temperature, but also on exposure over several previous days (Anderson and Bell 2009). Several previous studies on associations of temperature with mortality have considered delayed effects (Kysely 2004; Hajat et al. 2005; Bell et al. 2008; Hertel et al 2009), including lagged effects of temperature on single days and the effects of moving average temperature on subsequent days. However, these approaches are susceptible to overestimating the effects of the current day's exposure by ignoring the effects of exposure on previous days (Gasparrini et al. 2010), or underestimating the effects of exposure on mortality if they persist longer than the observed lag period (Schwartz 2000; Roberts and Martin 2007). Recently, a distributed lag non-linear model (DLNM) has been developed to simultaneously estimate the non-linear and delayed effects of temperature on mortality or morbidity (Armstrong 2006; Gasparrini et al. 2010).

Biologically, temperature stress may have an indirect but causal relationship with a variety of causes of death beyond hypo- and hyperthermia (Martin et al. 2012). Temperature stress can induce a variety of physiological changes in circulation patterns and respiratory rate, which in turn may exacerbate underlying conditions and result in increased mortality from a range of cardiovascular and respiratory diseases (Basu and Samet 2002; Kolb et al. 2007). Previous studies reported that temperature-related mortalities are more pronounced in the elderly (Revich and Shaposhnikov 2008; Anderson and Bell 2009). However, the heterogeneity among different age groups is worth further examination (Hajat et al. 2007; Baccini et al. 2008; Ishigami et al. 2008). In this study, we investigated both effects of heat and cold temperatures on different types of mortality (including non-accidental, cardiopulmonary, cardiovascular, and respiratory) and age-specific non-accidental mortality. The findings of this study provide useful information for policy makers to better understand the health effects of temperature in Hong Kong.

Materials and Methods

Data collection

Hong Kong (22° 15′ north, 114° 10′ east) is situated on the south coast of China, facing the northern part of the South China Sea and is located on the east side of the Pearl River estuary. With a land mass of 1,104 km^2 and a population of seven million people, Hong Kong is one of the most densely populated areas in the world (Hong Kong Census and Statistics Department 2011).

Mortality data on every death in Hong Kong for the period from 2002 through 2011 was obtained from the Hong Kong Census and Statistics Department (HKC&SD). Data included underlying and contributing age, sex, date of death, cause of death, place of birth, place of death, and census tract of residence. We classified non-accidental mortality according to the *International Classification of Diseases and Related Health Problems, 10th revision* (ICD-10 codes A00-R99; World Health Organization 2007). Cardiopulmonary (ICD codes I00-I99 and ICD codes J00-J99), cardiovascular mortality (ICD codes I00-I99), and respiratory mortality (ICD codes J00-J99) were examined separately. We also stratified non-accidental mortality into three age groups (0-64, 65-74, and ⩾ 75 years) similar to the study on weather, pollution, and acute myocardial infarction in Hong

Kong and Taiwan (Goggins et al. 2013). Daily meteorological data on maximum, mean, and minimum temperature, relative humidity was obtained from the Hong Kong Observatory. In order to adjust for the potential confounding effects of air pollution, we collected daily air quality data on particulate matter < 10 μm in aerodynamic diameter (PM_{10}), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). These criteria pollutants have been associated with cardiopulmonary mortality (Pope et al. 2002). Measurements of these air pollutants were compiled from the air monitoring data, routinely collected at 15 air quality monitoring stations. The air quality monitoring stations are located in different parts of Hong Kong to cover various kinds of land use. The Hong Kong Environmental Protection Department publishes the hourly average of air pollutants concentration in each monitoring stations. The mean concentrations for PM_{10}, SO_2 and NO_2 were used as the reference value to represent the level of air pollution in Hong Kong.

Statistical analysis

A quasi-Poisson regression model combined with a distributed lag non-linear model (DLNM) was used to assess the impacts of daily temperature on mortality at different lag days. The long-term and seasonal trend of daily mortality was controlled by using a natural cubic spline of time with 7 degrees of freedom (df) per year. PM_{10}, SO_2 and NO_2 were controlled by using the polynomial distributed lag model with 3 lag days and 3 df, and relative humidity using a natural cubic spline with 3 df (Stafoggia et al. 2008; Anderson and Bell 2009). These variables are potential confounders of the association between temperature and mortality (Bernard et al. 2001; Buadong et al. 2009). We also controlled the day of week as a categorical variable.

DLNM was used to predict the effects and standard errors of various combinations of temperatures and lags. The DLNM is developed based on a “cross-basis” function, which allows simultaneous estimation of the non-linear effects across lags. It shows the relationship between temperature and mortality at each temperature point and lag. It also calculates the cumulative effect of the existence of delayed contributions (Gasparrini et al. 2010). Graphs, summaries, and statistical inference can be obtained from DLNM estimates and standard errors (Armstrong 2006).

A “natural cubic spline–natural cubic spline” DLNM was adopted to model both the non-linear temperature effect and the lagged effect. Spline knots of lag were set at equally spaced values on the log scale of lags. A maximum lag of 21 days was measured to completely capture the overall temperature effect. The median value of temperature was defined as the baseline temperature (centering value) for calculating the relative risks. Akaike information criterion for quasi-Poisson (AIC-Q) models was used to choose the df (knots) for temperature and lag (Peng et al. 2006; Gasparrini et al. 2010). It was found that using 5 df for temperature and 4 df for lag produced the best model fit in the present study. The relative risks against temperature and lags were plotted to show the entire relationship between temperature and mortality. The overall effect of temperature on morality summed over lag days was also plotted.

To examine the hot effect on cause-specific and age-specific mortality, the relative risk of cause-specific and age-specific mortality associated with high temperature (31.5°C, 99th percentile of temperature) relative to the 75th percentile of temperature (27.8°C) was calculated. To examine the cold effect on cause-specific and age-specific mortality, the relative risk of cause-specific and age-specific mortality associated with cold temperature (11.1°C, 1st percentile of temperature) relative to the 25th percentile of temperature (19.4°C) was evaluated (Goldberg et al. 2011; Guo et al. 2012). These effect estimates were taken from the non-linear temperature-mortality curves, so they reflect a portion of true exposure-response curves (Tian et al. 2012).

We evaluated the model fit using Q-AIC. Our initial results showed that mean temperature (average of maximum and minimum temperatures) was a better predictor than maximum and minimum temperatures. Therefore, mean temperature was used in this study. Sensitivity analyses were performed by changing df (6–15 per year) for time to control for season. We changed df (4–7) for relative humidity, PM_{10}, SO_2, and NO_2, and varied the maximum lags from 22 to 30 days for the DLNM.

All statistical tests were two-sided, and values of $p < 0.05$ were considered statistically significant. Pearson correlation coefficients were used to summarize the similarities in daily weather conditions. We used R software (version 2.15.1; R Development Core Team 2009) to fit all models, with its "dlnm" package to create the DLNM (Gasparrini and Armstrong 2011).

Results

The average daily maximum temperature was 25.9°C; mean temperature, 23.4°C; minimum temperature, 21.6°C; relative humidity, 78%; PM_{10}, 52.9μg/m3; NO_2, 59.1μg/m3; SO_2, 19.9μg/m3. The average daily mortality count for non-accidental deaths was 100; cardiopulmonary deaths, 47; cardiovascular deaths, 27; and respiratory deaths, 20 (Table 1). In a total of 3652 days, there were 363,330 deaths (including 98,091 cardiovascular deaths and 72,660 respiratory deaths) registered in Brisbane. The percentages of total deaths by age group were 19.5%, 19.3%, 61.2% for 0-64 years, 65-74 years, and over 75 years, respectively. Table 2 shows the Pearson correlation coefficients of weather condition and air pollution. Three temperature measures were strongly correlated with each other. Mean temperature was moderately correlated with air pollutants and relative humidity. PM_{10}, NO_2, and SO_2, were strongly correlated with each other.

(Please insert Table 1&2 here)

The three-dimensional plots show the entire surface between the mean temperature and the mortality categories on all lag days (Figure 1). The estimated effects of temperature were non-linear for all mortality types, with higher relative risks at hot and cold temperatures. For example, an extremely hot temperature (30°C) was positively associated with non-accidental mortality on the current day, whereas an extremely cold temperature (5°C) significantly increased non-accidental mortality after a 3-day lag. Neither hot effects (i.e., significant increases in mortality associated with hot temperatures) nor cold effects (i.e., significant increases in mortality associated with cold temperatures) were apparent after a 13-day lag, with relative risks close to 1 across the entire range of temperatures.

(Please insert Figure 1 here)

Figure 2 shows the cumulative effects of mean temperature on mortality types at lags 0-3, lags 0-13, and lags 0-21. For lags 0–3, both extreme cold and hot temperatures increased the risks of all mortality types. The cumulative effects of extreme cold temperature on cause-specific mortality at lags 0–13, and lags 0–21 were higher than lags 0–3, while the cumulative effects of extreme high temperature on cause-specific mortality at lags 0–13, and lags 0–21 were lower than lags 0–3, except for respiratory mortality. Generally, the temperature effects on cause-specific mortality were similar at lags 0–13 and lags 0–21, which implies that the temperature effect on cause-specific mortality was stable after the lag of 13 days. For lags 0–21, the relationships between temperature and mortality types were all non-linear.

(Please insert Figure 2 here)

Figure 3 shows the cumulative effects of temperature on age-specific mortality at lags 0–3, lags 0–13, and lags 0–21. The effects of temperature on all age groups were non-linear. The cumulative effects of extreme cold temperature on age-specific mortality at lags 0–21 were higher than lags 0–13, and lags 0–3, while the cumulative effects of extreme high temperature on age-specific mortality at lags 0–13, and lags 0–21 were lower than lags 0–3.

(Please insert Figure 3 here)

The overall effects of mean temperature on non-accidental, cardiopulmonary, cardiovascular, and respiratory mortality were calculated along the lags (Table 3). Compared with the 25th percentile of temperature (19.4°C), the relative risks associated with cold temperature (1st percentile of temperature, 11.1°C) over lags 0–13 days were 1.17 (95% CI: 1.04, 1.29) for non-accidental mortality, 1.23 (95% CI: 1.05, 1.47) for cardiopulmonary mortality, 1.48 (95% CI: 1.06, 1.92) for cardiovascular morality, and 1.15 (95% CI: 0.98, 1.38) for respiratory mortality, respectively. Compared with the 75th percentile of temperature (27.8°C), the relative risks associated with extreme hot temperature (99th percentile of temperature, 31.5°C) over lags 0–3 days were 1.09 (95% CI: 1.01, 1.17) for total mortality, 1.14 (95% CI: 1.05, 1.27) for cardiopulmonary mortality, 1.08 (95% CI: 0.98, 1.23) for cardiovascular morality, and 1.33 (95% CI: 1.00, 1.89) for respiratory mortality, respectively.

(Please insert Table 3 here)

We also calculated the cumulative effects of mean temperature on age-specific non-accidental mortality along the lags (Table 4). Compared with the 25th percentile of temperature (19.4°C), the relative risks associated with cold temperature (1st percentile of temperature, 11.1°C) over lags 0–13 days were 1.09 (95% CI: 1.01, 1.20) for 0-64 years mortality, 1.29 (95% CI: 1.16, 1.42) for 65-74 years mortality, and 1.37 (95% CI: 1.26, 1.47) for 75 mortality, respectively. Compared with the 75th percentile of temperature (27.8°C), the relative risks associated with extreme hot temperature (99th percentile of temperature, 31.5°C) over lags 0–3 days were 1.08 (95% CI: 1.03, 1.19) for 0-64 years mortality, 1.13 (95% CI: 1.05, 1.27) for 65-74 years mortality, and 1.10 (95% CI: 1.01, 1.10) for 75 mortality, respectively. Those older than 75 years tended to be at higher risk of dying on very cold days, and those who aged 65-74 years were the most vulnerable group to very hot days.

(Please insert Table 4 here)

We changed df (6–15 per year) for time to control for season, which gave similar results. We changed df (3–7) for humidity, PM_{10}, NO_2, and SO_2, and the estimated effects of temperature were not substantially changed. In addition, we changed the maximum lag from 22 to 30 days, which gave similar results. The models used in this study appeared to have adequately captured the main effects of temperature on mortality.

Discussion

In this study, we examined the effects of temperature on cause-specific mortality in Hong Kong in the last decade between 2002 and 2011. We found that the temperature-mortality relationships were non-linear for four types of mortality. Consistent with previous studies on temperature-mortality (Lin et al. 2011; Yang et al. 2012; Wu et al. 2013), we also found that high and low temperature were associated with increased mortality in subtropical areas of China. Significant associations between cold temperatures and mortality appeared after 3 days and lasted longer than the associations between high temperatures and mortality, which were acute and of short duration. This pattern has been evidenced in previous studies, in which the heat effects were mostly immediate whereas the cold effects were delayed by several weeks (Muggeo and Hajat 2009). This suggests that early warning systems for severe weather should take this immediate heat effect and delayed cold effect into account.

The magnitude of temperature effects varies greatly by climate, region, and population. Notably, cold effect with 17% increase in non-accidental mortality risk was identified when comparing 1st percentile of temperature (11.1°C) with 25th percentile of temperature (19.4°C). An analysis in Chiang Mai, Thailand reported a similar cold effect with 19% increase in non-accidental mortality for the 1st percentile of temperature (19.4°C) to 25th percentile of temperature (24.7°C) respectively. We compared our results with those studies on Asian cities that examined both cold and hot effects using mean temperature for non-accidental mortality (Kan et al. 2003; Michael et al. 2008; Guo et al. 2011; Wu et al. 2013; Wang et al. 2014). Our results suggested that Hong Kong has lower cold and hot effects, which may be a result of better infrastructure development and greater access to air conditioning. Furthermore, the Hong Kong government issues warnings whenever the region is threatened by cold or very hot weather, to alert the public to the imminent danger and remind them to take necessary precautions. We also found that the cold effect is more pronounced than the hot effect in southern Asia. This phenomenon can be explained by long-term adaptation, as people in warm areas are generally more sensitive to cold weather (Anderson and Bell 2009). These findings suggest that extreme cold is an important public health problem in southern regions. Based on these findings, decision makers in southern Asia should not only pay attention to heat waves but also consider adaptive measures for extreme cold events.

Immediate heat effects can be seen in every outcome for the summer period, even in respiratory mortality. Consistent with the previous study (Ballester et al. 1997; Huynen et al. 2001; Chung et al. 2009; D'lppoliti et al. 2010), several authors observed a greater effect on respiratory mortality than on cardiovascular mortality in warmer seasons. The fact that these effects occur within a short space of time indicates a fast-acting mechanism (Ballester et al. 1997). Respiratory difficulty occurs as a result of the accumulation of heat and humidity over time (Monteiro et al. 2013). Furthermore, evaporative capacity is reduced, making an organism's sudation and cooling functions less effective. Simultaneously, evaporation capacity becomes smaller, making it difficult for an organism's sudation and cooling functions to occur (Frota and Schiffer 1987).

Our study showed that stronger associations were observed between cold temperature and cardiovascular mortality than between cold temperature and respiratory mortality. In a US multi-city study, Braga et al. (2002) observed a stronger effect of cold weather on cardiovascular disease than on respiratory mortality. By contrast, in Chicago, Illinois, O'Neill et al. (2003) found that the effect of cold weather was stronger on respiratory mortality. Thus far, the underlying mechanisms by which cold weather influences the pathogenesis of cardiovascular manifestations have not been fully clarified. The proposed mechanisms may include ischemia resulting from raised arterial blood pressure and a subsequent increase in myocardial oxygen demand, with a simultaneous decrease in coronary blood flow, and hematological changes following the cold-induced vasoconstriction and consequent loss of plasma fluid, which predispose the subject to arterial thrombosis (Nayha 2002; Mercer 2003). Measures necessary for preventing the harmful effects of temperature fluctuations should consider entire populations as well as those with chronic diseases (e.g. cardiovascular and respiratory).

Some studies have shown the elderly were more sensitive to the effect of temperature (Guo et al. 2012; Ma et al. 2012; Goggins et al. 2013). Our results confirmed the vulnerability of the elderly. The reason might be the thermal regulation system weakens with aging (Tian et al. 2012). The elderly are less able to maintain homeostasis in response to environmental challenges (Mukherjee et al. 1973; Goggins et al. 2013).

This study pioneers the application of an advanced statistical approach (DLNM) to assess temperature-mortality and investigate the mortality risk associated with prolonged heat and cold temperatures in Hong Kong. DLNM can flexibly show different temperature-mortality relationships for lags using different smoothing functions, and adequately model the main effects of temperature (Armstrong 2006; Guo et al. 2011). We examined both cold and hot lag effects across four types of mortality and determined which temperature measure was the best predictor of mortality. Furthermore, we used ten years' data which had high quality (no missing data for mortality), and also adjusted for a range of confounders including relative humidity and air pollution. Our findings can be used to promote capacity building for local response to extreme temperatures.

Our study also has several limitations. Influenza is one of the large causes of non-accidental and respiratory mortality. Influenza survival and transmission is sensitive to the amount of moisture in the air and temperature. Unfortunately, we do not have data to control this factor. Further studies need to be conducted to address this issue. In addition, the data and air pollution index are derived from fixed sites rather than from individual exposure. As such, certain inevitable measurement errors may have resulted. The estimated effects of weather on mortality may have been influenced by the socio-demographic characteristics and environmental conditions of each population. Further research on these factors will allow us to better understand the temperature-mortality relationship and might be useful in designing extreme temperature emergency plans and informing the development of strategies for adaptation.

Conclusions

This study examined the effects of temperature on cause-specific mortality in Hong Kong. High and low temperatures are associated with increased mortality, and the cold effects are more long lasting and pronounced than hot effects. Immediate heat effects increase the risk of respiratory mortality, whereas prolonged cold effects raise the risk of cardiovascular mortality. The people older than 75 years were the most vulnerable group to cold temperature, while people aged 65-74 were the most vulnerable group to hot temperature. These findings may have implications for the development of intervention strategies to reduce temperature-related mortality and provide useful information for local government to protect the well-being of the public in the face of extremely cold and hot temperatures.

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Figure legends

Figure 1 Relative risks of mortality types by mean temperature (°C), using a natural cubic spline-natural cubic spline DLNM with 5 df natural cubic spline for temperature and 4 df for lag. (A) non-accidental, (B) cardiopulmonary, (C) cardiovascular, and (D) respiratory mortality.

Figure 2 The estimated overall effects of mean temperature (°C) over 21 days on mortality types at lag 0-3 (left), 0-13 (middle), 0-21(right), using a natural cubic spline-natural cubic spline DLNM with 5 df natural cubic spline for temperature and 4 df for lag. (A) non-accidental, (B) cardiopulmonary, (C) cardiovascular, and (D) respiratory mortality. The red lines are the mean relative risks, and the grey regions are 95% CIs.

Figure 3

The estimated overall effects of mean temperature (°C) over 21 days on age groups at lag 0-3 (left), 0-13 (middle), 0-21(right), using a natural cubic spline-natural cubic spline DLNM with 5 df natural cubic spline for temperature and 4 df for lag. (A) 0-64 years, (B) 65-74 years, and (C) ≧75 years. The red lines are the mean relative risks, and the grey regions are 95% CIs.

Table 1 Summary statistics of daily weather conditions and mortality in Hong Kong, 2002–2011

Variable	Minimum	25%	Median	75%	Maximum	Mean ± SD
Temperature (°C)						
Maximum	9.3	21.7	27.0	30.3	35.4	25.9 ± 5.3
Mean	8.2	19.4	24.6	27.8	31.8	23.4 ± 5.1
Minimum	5.8	17.7	22.9	25.9	29.4	21.6 ± 5.1
Relative humidity (%)	31	73	79	85	98	78.0 ± 10.2
PM_{10} (µg/m3)	13.7	32.6	48.1	70.2	212.7	52.9 ± 27.1
NO_2 (µg/m3)	10.3	45.2	56.9	71.3	169.3	59.1 ± 21.7
SO_2 (µg/m3)	1.3	10.7	16.5	25.9	143.9	19.9 ± 15.1
Death						
Non-accidental	56	88	98	109	191	99.6 ± 16.4
Cardiopulmonary	18	39	46	53	106	46.8 ± 11.2
Cardiovascular	7	22	26	31	61	27.1 ± 7.1
Respiratory	5	15	19	23	58	19.7 ± 6.4
Age						
0-64	4	14	18	22	37	19.4 ± 4.4
65-74	5	14	18	22	39	19.2 ± 4.6
≥75	22	46	55	63	117	56.5 ± 11.8

25% and 75% represent the 25th and 75th percentiles, respectively.

Table 2 Pearson correlation coefficients between weather conditions in Hong Kong, 2002-2011.

	Mean temperature	Minimum temperature	PM_{10}	NO_2	SO_2	Relative humidity
Maximum temperature	0.98^*	0.95^*	-0.14^*	-0.36^*	-0.34^*	0.08^*
Mean temperature		0.99^*	-0.15^*	-0.37^*	-0.35^*	0.14^*
Minimum temperature			-0.15^*	-0.36^*	-0.34^*	0.17^*
PM_{10}				0.61^*	0.49^*	-0.28^*
NO_2					0.57^*	-0.15^*
SO_2						-0.23^*

*$p<0.05$ for all correlation coefficients.

Table 3 The cumulative relative risks of cold and hot effects on mortality types along the lag days

	Lag 0-3	Lag 0-7	Lag 0-13	Lag 0-21
Cold effect [a]				
Non-accidental	1.03 (0.95, 1.10)	1.04 (0.94, 1.13)	1.17 (1.04, 1.29)	1.21 (1.10, 1.65)
Cardiopulmonary	1.07 (0.98, 1.15)	1.13 (0.99, 1.27)	1.23 (1.05, 1.47)	1.30 (1.03, 1.67)
Cardiovascular	1.23 (1.01, 1.43)	1.27 (1.05, 1.49)	1.48 (1.06, 1.92)	1.56 (1.05, 2.14)
Respiratory	1.06 (0.96, 1.15)	1.09 (0.97, 1.19)	1.15 (0.98, 1.38)	1.16 (0.99, 1.59)
Hot effect [b]				
Non-accidental	1.09 (1.03, 1.17)	1.08 (1.03, 1.16)	1.07 (0.98, 1.16)	1.04 (0.94, 1.08)
Cardiopulmonary	1.14 (1.05, 1.27)	1.12 (1.04, 1.24)	1.10 (1.01, 1.19)	1.10 (1.01, 1.20)
Cardiovascular	1.08 (0.98, 1.23)	1.06 (0.96, 1.25)	1.05 (0.94, 1.19)	1.04 (0.91, 1.16)
Respiratory	1.33 (1.00, 1.89)	1.30 (1.02, 1.67)	1.28 (0.99, 1.61)	1.27 (0.97, 1.59)

[a] The cumulative effects of cold temperature on mortality categories, with 1st percentile of mean temperature (11.1°C) relative to 25th percentile of temperature (19.4°C).

[b] The cumulative effects of hot temperature on mortality categories, with 99th percentile of mean temperature (31.5°C) relative to 75th percentile of temperature (27.8°C).

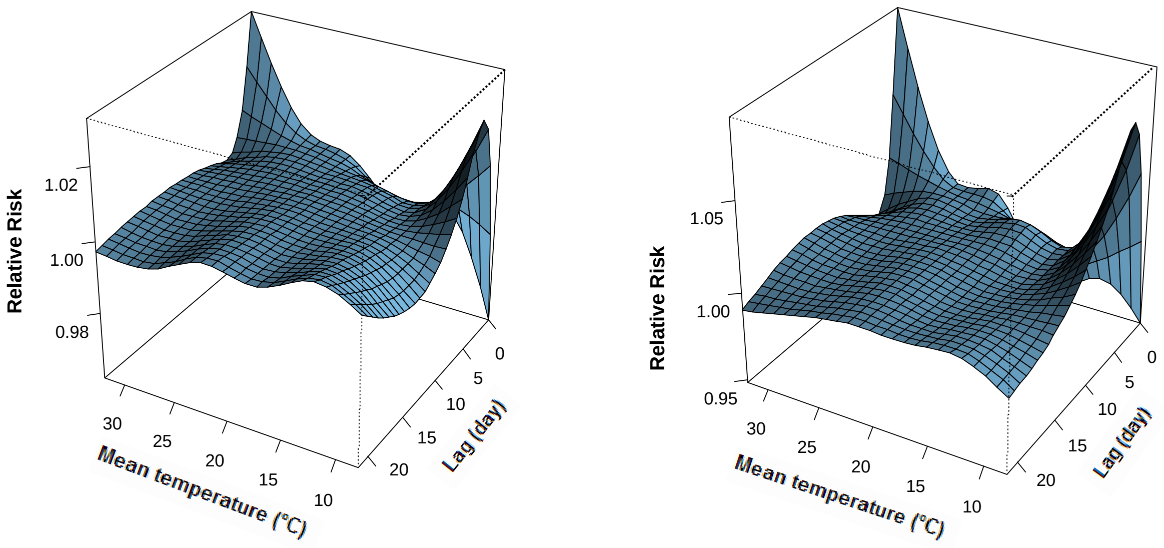
Table 4 The cumulative relative risks of cold and hot effects for non-accidental deaths stratified by age groups.

	Lag 0-3	Lag 0-7	Lag 0-13	Lag 0-21
Cold effect [a]				
0-64	1.05 (0.95, 1.17)	1.08 (1.00, 1.16)	1.09 (1.01, 1.20)	1.10 (0.96, 1.25)
65-74	1.12 (1.07, 1.24)	1.23 (1.14, 1.34)	1.29 (1.16, 1.42)	1.33 (1.17, 1.51)
⩾75	1.14 (1.09, 1.26)	1.23 (1.17, 1.30)	1.37 (1.26, 1.47)	1.41 (1.35, 1.51)
Hot effect [b]				
0-64	1.08 (1.03, 1.21)	1.06 (1.00, 1.16)	1.04 (0.92, 1.19)	1.01(0.93, 1.14)
65-74	1.13 (1.05, 1.25)	1.12 (1.05, 1.21)	1.11 (1.02, 1.20)	1.09 (0.98, 1.20)
⩾75	1.10 (1.01, 1.15)	1.08 (0.99, 1.14)	1.07 (0.95, 1.11)	1.05 (0.94, 1.09)

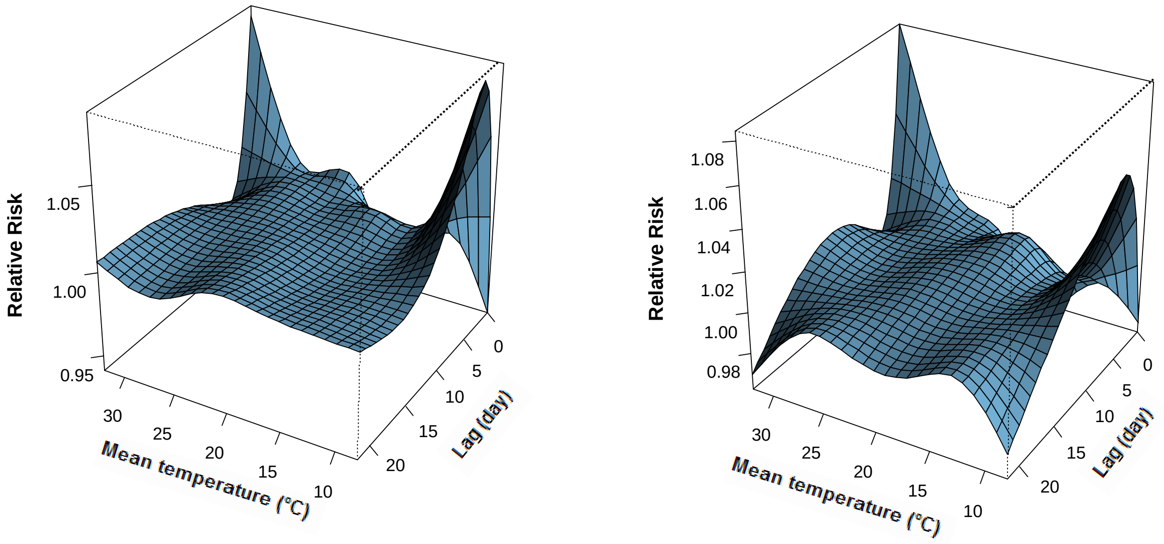
[a] The cumulative effects of cold temperature on mortality categories, with 1st percentile of mean temperature (11.1°C) relative to 25th percentile of temperature (19.4°C).

[b] The cumulative effects of hot temperature on mortality categories, with 99th percentile of mean temperature (31.5°C) relative to 75th percentile of temperature (27.8°C).

Figure 1


(A) Non-accidental

(B) Cardiopulmonary


(C) Cardiovascular

(D) Respiratory

Figure 2

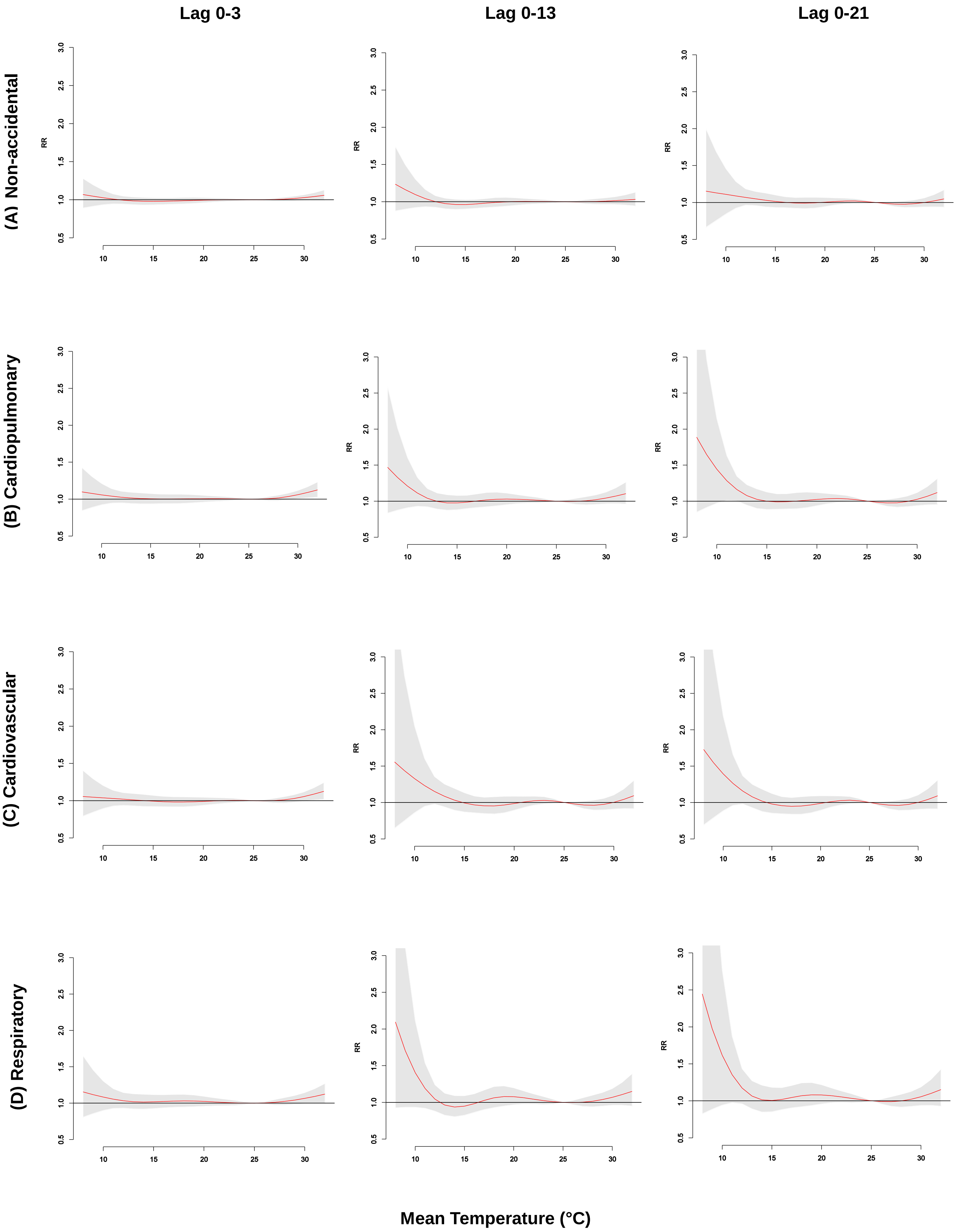
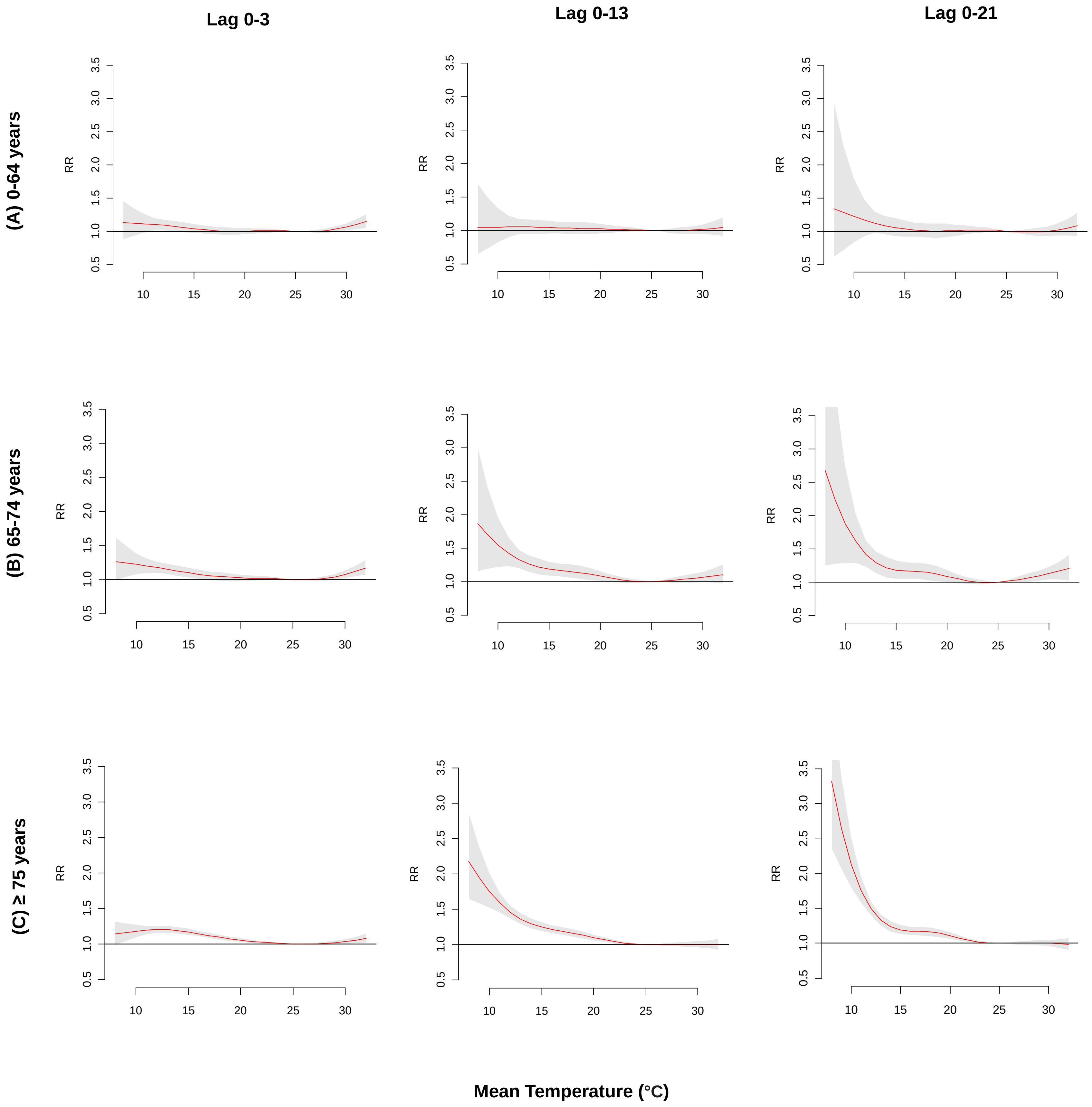

Lag 0-3
Lag 0-13
Lag 0-21
(A) Non-accidental
(B) Cardiopulmonary
(C) Cardiovascular
(D) Respiratory
RR
0.5
1.0
1.5
2.0
2.5
3.0
10
15
20
25
30
Mean Temperature (°C)

Figure 3


Lag 0-3
Lag 0-13
Lag 0-21
(A) 0-64 years
(B) 65-74 years
(C) ≥ 75 years
RR
0.5
1.0
1.5
2.0
2.5
3.0
3.5
10
15
20
25
30
Mean Temperature (°C)