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Are the Current Thresholds, Indicators, and Time Window for Cold Warning Effective Enough to Protect Cardiovascular Health?

Shao Lin[1,2,*], **Wayne R. Lawrence**[2], **Ziqiang Lin**[1,3], **Stephen DiRienzo**[4], **Kevin Lipton**[4], **Guang-Hui Dong**[5], **Ricky Leung**[6], **Ursula Lauper**[1], **Philip Nasca**[2], and **Neil Stuart**[4]

[1]Department of Environmental Health Science, School of Public Health, University at Albany, State University of New York, 1 University Place, Rensselaer, New York 12144, United States of America

[2]Department of Epidemiology and Biostatistics, School of Public Health, University at Albany, State University of New York, 1 University Place, Rensselaer, New York 12144, United States of America

[3]Department of Mathematics and Statistics, College of Arts and Sciences, University at Albany, State University of New York, 1400 Washington Avenue, Albany, New York 12222, United States of America

[4]National Weather Service, National Oceanic and Atmospheric Administration, 251 Fuller Rd B-300, Albany, New York 12203, United States of America

[5]Department of Preventive Medicine, School of Public Health, Sun Yat-sen University, No. 74 Zhongshan 2nd Road, Yuexiu District, Guangzhou, Guangdong 510080 China

[6]Department of Health Policy, Management and Behavior, School of Public Health, University at Albany, State University of New York, 1 University Place, Rensselaer, New York 12144, United States of America

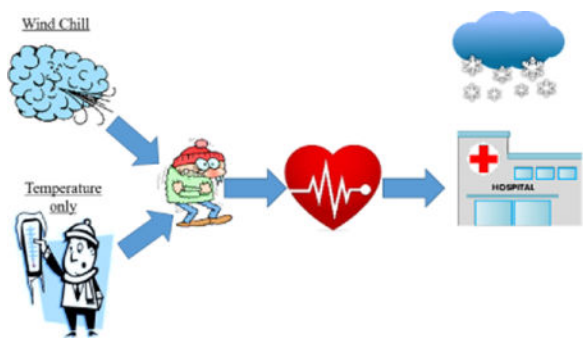
Abstract

More extreme cold weather and larger weather variations have raised concerns regarding their effects on public health. Although prior studies assessed the effects of cold air temperature on health, especially mortality, limited studies evaluated wind chill temperatures on morbidity, and health effects under the current cold warning threshold. This study identified the thresholds, lag periods, and best indicators of extreme cold on cardiovascular disease (CVD) by comparing effects of wind chill temperatures and cold air temperatures on CVD emergency department (ED) visits in winter and winter transition months. Information was collected on 662,625 CVD ED visits from statewide hospital discharge dataset in New York State. Meteorological factors, including air

*Corresponding Author: **Comments and correspondence should be addressed to:** Shao Lin, MD, PhD, Professor, Department of Environmental Health Science, School of Public Health, Rm 212d, University at Albany, State University of New York, One University Place, Rensselaer, New York 12144, slin@albany.edu; Phone: +1 518-402-1685; Fax: +1 518-402-0329.

temperature, wind speed, and barometric pressure were collected from National Oceanic and Atmospheric Administration. A case-crossover approach was used to assess the extreme cold-CVD relationship in winter (December-February) and transition months (November and March) after controlling for $PM_{2.5}$. Conditional logistic regression models were employed to analyze the association between cold weather factors and CVD ED visits. We observed CVD effects occurred when wind chill temperatures were as high as −3.8°C (25°F), warmer than current wind chill warning standard (≤−28.8°C or ≤−20°F). Wind chill temperature was a more sensitive indicator of CVD ED visits during winter with temperatures ≤−3.8°C (25°F) with delay effect (lag 6); however, air temperature was better during transition months for temperatures ≤7.2°C (45°F) at earlier lag days (1–3). Among all CVD subtypes, hypertension ED visit had the strongest negative association with both wind chill temperature and air temperature. This study recommends modifying the current cold warning temperature threshold given larger proportions of CVD cases are occurring at considerably higher temperatures than the current criteria. We also recommend issuing cold warnings in winter transitional months.

Graphical abstract



Keywords

Cold Weather; Cardiovascular Disease; Wind Chill Temperature

Introduction

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in the United States (U.S.) attributing to more deaths than other major causes, and the leading cause of short-stay hospital admissions (Mensah and Brown, 2007; Mozaffarian et al., 2016). CVD accounts for approximately 1 in 3 deaths in the U.S., and has consistently been a major cause of health disparities (Mensah and Brown, 2007; Mozaffarian et al., 2016). CVD prevalence varies drastically based on socioeconomic status. Previous studies have reported on the negative effects of biological, societal, and environmental factors on CVD morbidity and mortality. For instance, exposure to air pollutants (e.g. $PM_{2.5}$) and high ambient heat were found to be associated with increased risk of CVD hospital admissions (Lin et al., 2009; Weichenthal et al., 2014).

The health effects related to extreme weather is a growing public health concern, where majority of recent studies have focused on the relationship between adverse health and high temperatures/heat event, with fewer investigating the effects of cold weather on individuals with CVD, especially in the U.S. Among these studies, findings suggest compared to heat, the health effects of cold temperatures are stronger and delayed (Tian et al., 2016; Wang et al., 2015). Extreme cold temperatures are associated with elevated blood pressure, higher total cholesterol, and increased heart rate (Cheng and Su, 2010; Hong et al., 2012). To date, few studies have found an association between cold spells and increased cardiovascular events (Callaly et al., 2013; Kysely et al., 2009; Lin et al., 2016). However, they were focused either on case-specific mortality or have been limited to using air temperature, thereby failing to examine morbidity or account for the influence of wind chill, an important weather factor in winter (Kunst et al., 1994). For instance, as wind blows across the body on a cold day, it draws heat away making the apparent temperature considerably lower than the ambient air temperature reported (National Oceanic and Atmospheric Administration, 2012). By using wind chill indices, the combination of cold temperature and winds blowing on exposed skin is measured. More importantly, it is unknown whether the existing cold advisory or warning thresholds and indicators (either temperature or wind chill temperature) are sensitive or appropriate enough for protecting human health. Furthermore, the cold weather advisory and warning threshold in winter may be different from that in late fall or early spring on predicting human health.

To fill these knowledge gaps and by working with the National Oceanic and Atmospheric Administration (NOAA), we examined the cold thresholds and lag days for total CVD and CVD subtypes to determine if the current standard is appropriate. We also compared whether wind chill temperature or air temperature is a better indicator for cold-related CVD ED visits, stratified by winter and winter transitional months. New York State (NYS) is the ideal location for this study due to having highly diverse geographic regions, temperature zones, and demographic characteristics.

Materials and Methods

Study population and case definition

The study population consisted of ED cases with a principal diagnosis of CVD, who resided in NYS from 2005–2013. These cases included CVD (International Classification of Disease 9th revision [ICD9] codes, acute myocardial infarction (ICD9 410), chronic rheumatic heart disease (ICD-9 codes 393–396), hypertension (ICD9 401–405), ischemic heart diseases (ICD9 410–414), cardiac dysrhythmias (ICD9 427), congestive heart failure (ICD9 428), or cerebrovascular diseases (ICD9 430–434,436–438) from 2005–2013 in NYS during the months of November through March.

Sources of Data

Data on NYS ED visits were obtained from New York Department of Health (NYSDOH) Statewide Planning and Research Cooperative System (SPARCS), which collects patient level information, such as principle and other diagnosis, age, gender, race, ethnicity, and residential address. SPARCS is a legislatively mandated database with complete coverage for approximately 95% of NYS hospitals (excluding federal and psychiatric facilities). The SPARCS administrative staff reviews information reported by hospitals for accuracy and completeness. All hospitals in NYS use SPARCS for billing and reimbursement purposes (New York State Department of Health, 2015). Daily data on meteorological factors, including air temperature (T), wind speed (V), and barometric pressure (P) were provided by NOAA and the Data Support Section of the Computational and Information System Laboratory. There are 52 weather-monitoring sites throughout NYS, which all were included in the present study.

Exposure Definition

All temperatures collected from the NOAA were originally reported in Fahrenheit, and converted to Celsius for the present study. Winter was defined from December to February, and the transitional months were November (late fall) and March (early spring). The cold warning temperature threshold in NYS is generally issued when air temperature is ≤−12.2°C (10°F) for ≥3 days. Wind chill temperature and ambient air temperature were the two weather indicators. Wind chill was used to determine the air temperature felt on the skin by incorporating both air temperature and wind blowing on exposed skin (National Oceanic and Atmospheric Administration, 2012), which is determined at temperatures ≤50°F (≤10°C) and wind speeds greater than 3 MPH (National Weather Service, 2001). Wind chill is calculated using the formula:

$$Wind\ chill\ (^\circ F) = 35.74 + 0.6215T - 35.75\left(V^{0.16}\right) + 0.4275T\left(V^{0.16}\right),\ where\ V = wind\ speed\ (MPH),\ T = air\ temperature\ (^\circ F)$$

In addition, daily average temperature (°F) was also used as the indicator of ambient temperature in this study. We chose the highest wind chill temperature (−1.1°C or 30°F) and air temperature (10°C or 50°F) as the reference groups for our analysis. We identified 14 weather regions with 52 monitoring sites in NYS with relatively homogenous weather by overlaying and merging with health data (Chinery and Walker, 2009; Guttman and Quayle, 1996; Lin et al., 2016). Regions that were small and failed to completely concur were merged with contiguous regions of closest similarity (Lin et al., 2016). Based on geocoded residential addresses, each ED visit was assigned to one of the 14 regions in which average temperature values among all monitoring sites within that region were calculated. We assessed similarity and correlation coefficients of temperature parameters among monitoring stations in each region. This method resulted in a relatively homogenous weather exposure within each of the 14 regions. MapMarker Plus was used to geocode each hospital by address and assign each to a region.

Confounders and Effect Modifiers

Since many sociodemographic factors, such as age, gender, and race/ethnicity are risk factors of CVD based on prior literature (Mensah et al., 2005; Mensah and Brown, 2007), these variables are potential confounders and effect modifiers. As cases serve as their own controls in the case-crossover design, some inherit factors such as race and gender were automatically controlled. Major time variant variables such as weekday or weekend, seasonality, and long-term trend were also controlled by the case-crossover design as both exposed and non-exposed periods occurred in the same period. Barometric pressure and fine particles ($PM_{2.5}$) were first assessed if they were related to both CVD and extreme cold as potential confounders, but only $PM_{2.5}$, a potential confounder, was controlled in the conditional logistic regression model (Maclure, 1991).

To identify the modifying effects of demographics, variables such as sex, race-ethnicity, age, and urbanicity were included in stratified analysis. Race and ethnicity groups were categorized as white-Hispanics, white non-Hispanic, black-Hispanic, black non-Hispanics, and other. We categorized age in ranges as follows: 0–17, 18–44, 45–64, and ≥65.

Statistical Analysis

We used a time-stratified case-crossover design to assess the relationship between cold weather and health. The Matched-Pair Interval Approach that contrasts a pair of hazard and control intervals contributed by the same patient in the same month was used in this study. In this design, each case serves as their own control, and 1–6 lag days prior to ED visit were assessed. Exposure indicators were compared among cases at the same lags between the hazard and control period. Three referents per case per month on average were provided by having a time-stratified selection of referents. We used conditional logistic regression models to assess the association between wind chill temperatures and CVD-related ED visits using the adjusted odds ratios (OR). $PM_{2.5}$ was adjusted for in our analysis, as we recently found its effect was strongest in winter and associated with adverse cardiovascular health (Hsu et al., 2017). Adjusted OR and 95% confidence intervals (95% CI) were calculated for NYS as a whole and the 14 regions in different lags. We also evaluated a potential dose-response relationship by categorizing wind chill temperature and air temperature into 5°F (−15°C) increments, and then compared the OR for each category with the highest temperature category as the referent.

Results

Our analysis included 662,625 CVD ED visits. The rate of CVD ED visits was highest in the Mohawk Valley (18.0 per 100) (data not shown). The statewide wind chill temperatures during the cold weather season varied based on location in NYS with the highest in LaGuardia and Staten Island region (12.7°C or 55°F), and the lowest in Mohawk Valley region (5.05°C or 41.1°F). Similarly, the highest air temperature was reported in LaGuardia and Staten Island region (17.4°C or 63.4°F), with the lowest temperature reported in Mohawk Valley region (1.2°C or 34.3°F) (data not shown).

Table 1 shows the association between CVD ED visits and wind chill temperatures or air temperature for winter (December–February) by lag days in NYS. We found that most wind chill temperature groups (≤−12.2°C or 10°F) were consistently associated with increased CVD ED visits in lag 4–lag 6, compared to the referent wind chill temperature group (−3.8°C to −1.1°C or 25°F to 30°F). The strongest association and most detrimental effect on CVD related to wind chill temperature occurred at lag 6, but the associations were consistently less than one at lag 0–lag 3. The ORs for wind chill temperatures on CVD varied between 1.02 (95% CI 1.01, 1.03) for ≤−12.2°C (≤10°F) (lag 4–lag 6) and 1.05 (95% CI 1.02, 1.09) for ≤−28.8°C (≤−20°F) (lag 6). We also found that the ORs began to decline after lag 6 (data not shown). Different from wind chill temperature, low temperature-CVD relationship were either not statistically associated or less than one for all temperature ranges in winter regardless of lag periods when we used air temperature indicator.

Table 2 describes the results for the association between CVD ED visits and wind chill temperature or air temperature in November, a transitional month to winter by lag days. Results reveal that wind chill temperatures below −6.6°C to −3.8°C (20°F to 25°F) were associated with CVD in lag 3 and lag 5 with the highest odds ranging from 1.08 (95% CI 1.02, 1.14) to 1.15 (95% CI 1.09, 1.22) at −15°C to −12.2°C (5°F to 10°F) (lag 4–lag 6). Compared to winter season, wind chill temperature's health effect in November started earlier (lag 3), occurred at a higher temperature range (−6.6°C to −3.8°C or 20°F to 25°F), and had higher odds (OR 1.08–1.15). Similar with wind chill temperature, we also found that the effect from cold temperature on CVD started in lag 3, occurred at an even higher temperature range of 1.6°C to 4.4°C (35°F to 40°F), and had the highest odds of 1.80 (95% CI 1.06, 3.06) at −12.2°C to −9.4°C (10°F to 15°F) (lag 3). The most consistent positive cold temperature–CVD associations were observed in lag 5, having the widest temperature range (−9.4°C to 7.2°C or 15°F to 45°F).

Similar to Table 2, Table 3 shows wind chill temperature and air temperature on CVD ED visits for the month of March. Overall, we observed air temperature was a more sensitive indicator than wind chill temperature. For wind chill temperatures, we observed the strongest association at lag 4 with odds of 1.14 (95% CI 1.04, 1.25) for −31.6°C to −34.4°C (−25°F to −30°F). For air temperature, we observed the widest temperature range for CVD ED visits at lag 5 for temperatures 7.2°C to −12.2°C (45°F to 10°F).

Since the health effects from cold spells in both November and March started earlier and peaked at lag 5, we present the cold-CVD associations by CVD subtypes for both wind chill temperature and air temperature at lag 5 in Table 4, and lag 6 in Supplemental Table 1. The increased odds of hypertension were consistently observed in multiple wind chill groups (−23.3°C to −6.6°C or −10°F to 20°F) with associated ORs ranging from 1.02–1.09. Similarly, consistent and positive findings of air temperature on hypertension were also found for temperatures ranging −12.2°C to −1.1°C (10°F to 30°F) with ORs ranging from 1.03 to 1.06. Ischemic heart disease ED visits were also associated with wind chill temperature of −26.1°C to −23.3°C (−15°F to −10°F) (OR=1.18; 95% CI 1.02, 1.38) and −17.7°C to −15°C (0°F to 5°F) (OR=1.06; 95% CI 1.01, 1.10). Two air temperature groups (−17.7°C to −15°C or 0°F to 5°F) and (−12.2°C to −9.4°C or 10°F to 15°F) were found to be associated with risk of ischemic heart disease ED visits (ORs 1.22 and 1.06, respectively). We performed stratified analyses for the association between wind chill and CVD ED visits by demographics and weather region in winter, however, we did not observe a trend but rather a few isolated findings at lags 5 (Supplemental Table 2). For instance, compared to males, females generally had significantly higher odds of CVD ED visits at multiple wind chill temperature ranges (ORs ranging 1.04 to 1.01). Moreover, black Hispanics were strongly associated with CVD ED visits for −17.7°C to −15°C (0°F to 5°F) and −15°C to 12.2°C (5°F to 10°F), with ORs of 3.77 and 1.93, respectively.

Discussion

Cold thresholds for increased CVD risk

This study found CVD ED visits increased when wind chill temperatures were ≤−12.2°C (10°F) in the winter period (2005–2013). This finding is consistent with our previous publication in NYS using prior (1991–2004) SPARCS data, which found an association between acute myocardial infarction (AMI) and ambient universal apparent temperature (UAT) ≤−12.2°C (10°F) in winter (Lin et al., 2016). When Son et al. (2014) compared hospital admissions in eight cities in Korea at the 1st to 10th percentile ≤2°C (35.6°F) to 15°C (59°F) in winter, no associated change was found for CVD (Son et al., 2014). Tian et al. (2016) examined the health impacts of year-round temperature in Hong Kong and observed associated nonlinear and delayed cold effect using 23°C (73.4°F) as optimal temperature reference, but found no heat effect on emergency circulatory hospitalizations (Tian et al., 2016). Both studies used higher ranges of temperature thresholds than our study. Similarly, Giang et al (2014) found a relationship between cold exposure and CVD for temperatures ≤26°C (78.8°F), however, cumulative effect of hot temperatures was not associated (Giang et al., 2014).

The current wind chill index by Environmental Canada are wind chill temperatures between −20°F to −29°F (−28.8°C to −33°C) for at least 3 hours or wind speed ≥15 km/h and last 3 hours. In the U.S., Wind Chill Advisory and Wind Chill Warnings are issued to inform individuals of the health risk the weather possess. According to the National Weather Service, the threshold for most of Northeastern U.S. is −31.6°C (−25°F), however, for Northern New York, all of Vermont and New Hampshire, and Southern Maine it is −34.4°C (−30°F) (National Weather Service, 2001). In Northern Maine, the threshold is −37.2°C (−35°F). Wind Chill Warning is issued when wind chills ≤−28.8°C (−20°F) are expected east of the Blue Ridge Mountains, and wind chills ≤−31.6°C (−25°F) expected along and west of the Blue Ridge Mountains and in Frederick and Carroll Counties in Maryland (National Weather Service, 2001). Additionally, in NYS cold temperature warning is generally issued when air temperature is ≤−12.2°C (10°F) for ≥3 days. However, our study revealed CVD health effects were found at much higher ranges for wind chill temperature (≥ −28.8°C or −20°F) and air temperature (−9.4°C or ≥15°F) than current advisory and warnings.

Lag effects of cold weather on CVD

The present study found most CVD ED visits occurred 4– 6 lag days following wind chill temperatures ≤−12.2°C (10°F) with the strongest odds peaking at lag 5. Our findings are consistent with Lin et al (2016)'s study of extreme cold UAT on AMI with associations occurring only between lag 4–6 days (Lin et al., 2016). Similarly, Giang et al. (2014) found that the effect of cold on CVD occurred 4–15 days following exposure with a peak at a week's delay in Vietnam (Giang et al., 2014). Barnett et al (2005) reported that daily rates of CVD correlated with average temperature from the same day and previous 3 days in Queensland, Australia (Barnett et al., 2005). The latency for CVD hospitalization due to extreme weather is usually longer than respiratory diseases (Lin et al., 2009).

Effects of cold weather on CVD subtype

Among all CVD subtypes, we observed hypertension was associated with the largest numbers of wind chill temperature and air temperature ranges, as well as had the strongest association, where odds increased as temperature decreased. Our findings are consistent with a study by Su et al. (2014) which found a decreased in ambient temperature by 10°C (50°F) was associated with increased prevalence of newly detected hypertension (Su et al., 2014). Similar findings were observed in Norway, Japan, India, and the U.S., where a decrease in temperature was associated with an increased risk of hypertension (Fletcher et al., 2012; Kamezaki et al., 2010; Madsen and Nafstad, 2006; Sinha et al., 2010). Additionally, ischemic heart disease revealed a similar but less consistent pattern in this study, consistent with prior findings where risk of emergency hospital admissions elevated as weather got colder (Chen et al., 2017; Tian et al., 2016). However, the above-mentioned studies did not examine health risk of wind chill temperature as we did in the present study, making it difficult for us to compare findings. Surprisingly, we observed “other CVD” group (acute myocardial infarction, chronic rheumatic heart disease, and congestive heart failure) were associated with higher air temperature ranges (−9.4°C – 7.2°C or 15°F – 45°F) for lag 6. Presumably, this is contributed by other unknown factors as acute myocardial infarction and congestive heart failure should not have long latency after cold spell, due to disease severity.

Comparison of different indicators for warning criteria

Our study found wind chill temperature was associated with increased risks of CVD, ranging from 2% to 5% in winter. However, cold air temperature showed significantly protective effects on CVD during winter. Since all prior studies examining cold-CVD association used air temperature as the cold indicator, no comparison can be made regarding wind chill temperature. Temperature and wind chill are not always correlated with each other. Wind chill indicator can signify perceived apparent temperature on the skin when exposed to outside windy conditions. The perceived temperature of wind chill varies depending on how fast the wind travels, and how low or high the air temperature really is. Today, many countries currently use air temperature as a cold indicator for cold weather advisory and warning system in winter. However, in the early 2000s the Joint Action Group for Temperature Indices consisting of the National Weather Service and Environment Canada developed the current North America wind chill index (Environment and Climate Change Canada, 2015; Osczevski and Bluestein, 2005). In addition to air temperature, the current study recommends using wind chill temperature as an indicator for warning and CVD surveillance during extreme cold weather as this indicator is even more sensitive to CVD health than air temperature.

Cold’s effect on CVD in different seasons

Our study also demonstrated a very interesting finding, where indicators of extreme cold on CVD health could be quite different depending on time-period in cold season. We found that although wind chill temperature is more important during winter season (December–February), both wind chill temperature and air temperature were good indicators for odds of CVD ED visits in transition months (November and March). Additionally, the magnitudes of extreme cold’s effect on CVD in November seemed to be much stronger (ORs ranging1.02–

1.80) than those in winter season (ORs ranging 1.01–1.05). The CVD effects also occurred earlier (started and peaked at lag 3) in November than in winter (started at lag 4–lag 6). The cold effect on CVD in March was similar as that in November except for showing a decrease wind chill effect. To the best of our knowledge, no previous research examined similar issues, resulting in the inability to compare findings with the present study. The difference of risk magnitudes and lag days of cold on CVD by season can be explained by population adaptability. During winter season, the human body has adjusted to cold temperatures, and people most likely stayed indoors or dressed appropriately because of cold temperatures or the result of issued Winter Advisories and Warnings. However, people may not have adapted to cold weather during late fall nor prepared for sudden cold exposure (beginning or end of winter month), resulting in increased susceptibility to cold weather's impact with stronger and earlier effect occurring than in typical winter. Moreover, the current Winter Advisory for most countries are only implemented during winter months, and may therefore miss the critical time window for early warning or possible intervention during transitional seasons. Furthermore, developing a system during winter transition months may reduce CVD burden related to cold weather.

Potential biological plausibility

The association of cold weather with CVD has clinical relevance and have previously been suggested (Bunker et al., 2016; Keatinge et al., 1984). Cold weather is associated with increased heart rate, systemic vascular resistance, and blood pressure (Cheng and Su, 2010). Previous studies have shown that exposure to low temperature increases blood pressure caused by constriction of skin vessels and is accentuated with aging (Ikaheimo et al., 2014). Oxygen demand is also elevated due to enhancing blood pressure caused by the effects that cold stress can induce on increasing systemic vascular resistance (Cheng and Su, 2010). Additionally, cold weather increases sympathetic nervous activities, platelet aggregation, red blood cell counts, and plasma cholesterol (Cheng and Su, 2010; Hong et al., 2003; Lin et al., 2016).

Strengths and Limitations

To our knowledge, this may be the first study to assess and compare wind chill temperature and air temperature effects on CVD ED visits, especially in a state such as New York with multiple sub-climate regions and diverse racial/ethnic populations. Our study will fill multiple knowledge gaps, including identifying cold threshold or sensitive cold indicators related to CVD risk, understanding lag effects of different cold indicators on CVD, assessing cardiovascular effects during extreme cold in winter and transitional months, and identifying CVD vulnerable populations. All of these unique contributions will be useful for future extreme weather preparedness, adaptation planning, and potential surveillance. More importantly, this study may be the first in assessing if the current wind chill or air temperature threshold or warning criteria is appropriate to predict CVD in different seasons, and if the effects of extreme cold on CVD in transition months are different from that in winter. We are working with federal weather forecast agencies and state/county health departments to reevaluate current criteria of cold weather warnings/advisories and critical time window for warning in order to translate our findings to public health intervention and education.

In terms of potential limitation, this study may have only captured the most severe CVD cases, due to using ED visits as health endpoints. Therefore, the total effect of extreme cold on all CVD cases could be underestimated. However, we did find the strongest association between cold and hypertension (~45% of cases), a relatively less severe condition among all CVD types, which may lessen our concern regarding representativeness among mild CVD cases. Conversely, we also conducted a sensitivity analysis by rerunning the major analyses among AMI cases only, a condition that requires immediate medical attention and treatment through hospital admission, where our findings remained the same. Another concern is the potential confounders of cold-CVD relationship, such as personal activity pattern, heating use, quality of housing, sociodemographic variables, particulate matter levels, and family history of CVD. The case-crossover design provides a unique advantage compared to other study designs by using their own as the controls and therefore, controlling for time-irrelevant confounders, such as gender, race, ethnicity, age, smoking, family history of CVD, and pre-existing diseases. Since air quality may be a confounder in the current study and ozone level is low in winter, we controlled for $PM_{2.5}$, a dominant pollutant in winter. In terms of the potential long-term effect of extreme cold on CVD, we examined the lag effects beyond six days and found that the cold-CVD positive effects disappeared in NYS, which is why we only reported up to lag 6. More specifically, our sensitivity analyses indicated that lower and even protective effects of extreme cold on CVD occurred on Lag 7 and Lag 8 compared to those effects from Lag 0–6. Additionally, the purpose of this study is to evaluate the current forecast thresholds in relation to CVD ED visit, an urgent condition that requires immediate medical treatment. Therefore, it should be appropriate that we used the case-crossover design which is typically used to assess transit or immediate effect. Finally, meteorological data relied on ecologic-level data, from fixed monitoring locations, (Lin et al., 2016) assumed to be gathered uniformly across regions, and did not account for local microenvironment that may affect ambient temperature at residential locations or indoor temperatures. Furthermore, some unavailable or uncontrolled factors, such as heating use pattern, outdoor activity during cold season, and behavior risk factors, may modify the effects of cold temperature on CVDs.

Conclusion

We conclude that wind chill temperature is a better indicator for CVD health during winter compared to air temperature. A substantial proportion of CVD cases occurred at much higher temperature ranges than the current cold spell warning threshold. The CVD effects were stronger and occurred earlier after extreme cold in transition months than in winter. This study provides evidence for considering changes to current advisory or warning thresholds and weather forecasts for policy level or advisory, selecting appropriate cold index, and planning early warnings and intervention in transition seasons.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Majority of CVD cases occurred at higher temperatures than current cold standard
- Wind chill is a better indicator for CVD in winter compared to air temperature
- CVD effects were stronger and occurred earlier in transition months than in winter
- Among subtypes, hypertension had the strongest relationship with cold weather

Table 1

Wind chill Temperature and Air Temperature Effects on CVD Emergency Department Visits in Winter (December – February) from 2005 to 2013 in New York State

	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6
	OR * (95% CI†)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Wind chill Temperature							
−34.4°C (−30°F) —	0.93 (0.89,0.96)	0.96 (0.93,1.00)	1.02 (0.99,1.06)	1.02 (0.98,1.06)	1.02 (0.98,1.06)	1.01 (0.97,1.08)	1.04 (1.00,1.08)
−31.6°C (−25°F) —	0.92 (0.89,0.95)	0.95 (0.92,0.98)	0.97 (0.94,1.00)	0.99 (0.96,1.03)	1.02 (0.98,1.05)	1.01 (0.98,1.05)	1.05 (1.02,1.09)
−28.8°C (−20°F) —	0.92 (0.89,0.94)	0.97 (0.94,0.99)	1.01 (0.98,1.03)	1.01 (0.98,1.04)	0.98 (0.96,1.01)	1.04 (1.01,1.07)	1.02 (1.00,1.05)
−26.1 °C (−15°F) —	0.93 (0.91,0.95)	0.95 (0.93,0.97)	0.98 (0.96,1.00)	0.98 (0.96,1.00)	0.99 (0.97,1.01)	1.01 (0.99,1.04)	1.02 (1.00,1.04)
−23.3°C (−10°F) —	0.94 (0.93,0.96)	0.97 (0.95,0.99)	1.00 (0.98,1.02)	0.98 (0.96,1.00)	1.03 (1.01,1.05)	1.01 (0.99,1.03)	1.03 (1.01,1.05)
−20.5°C (−5°F) —	0.93 (0.91,0.94)	0.97 (0.95,0.98)	0.99 (0.97,1.00)	1.00 (0.99,1.02)	1.03 (1.01,1.04)	1.02 (1.00,1.03)	1.03 (1.01,1.04)
−17.7°C (0°F) —	0.94 (0.93,0.95)	0.97 (0.96,0.98)	1.00 (0.99,1.01)	1.00 (0.99,1.01)	1.01 (0.99,1.02)	1.01 (1.00,1.02)	1.02 (1.01,1.04)
−15°C (5°F) —	0.94 (0.93,0.95)	0.97 (0.96,0.98)	0.99 (0.98,1.00)	1.00 (0.99,1.01)	1.01 (1.00,1.02)	1.02 (1.01,1.03)	1.02 (1.00,1.03)
−12.2°C (10°F) −	0.95 (0.95,0.96)	0.98 (0.97,0.99)	1.00 (0.99,1.01)	1.00 (0.99,1.01)	1.01 (1.00,1.02)	1.01 (1.00,1.02)	1.02 (1.01,1.03)
−9.4°C (15°F) —	0.97 (0.96,0.98)	0.99 (0.98,1.00)	1.00 (0.99,1.01)	1.01 (1.00,1.01)	1.01 (1.00,1.02)	1.01 (1.00,1.02)	1.01 (1.00,1.02)
−6.6°C (20°F) —	0.99 (0.98,1.00)	1.00 (1.00,1.01)	1.01 (1.00,1.02)	1.01 (1.00,1.02)	1.01 (1.00,1.02)	1.01 (1.00,1.02)	1.01 (1.00,1.02)
−3.8°C (25°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Air temperature							
−23.3°C (−10°F) —	0.84 (0.79,0.89)	0.94 (0.89,1.00)	0.98 (0.92,1.03)	1.00 (0.94,1.06)	0.97 (0.92,1.02)	0.99 (0.93,1.04)	0.98 (0.92,1.03)
−20.5°C (−5°F) —	0.91 (0.87,0.94)	0.91 (0.88,0.95)	0.98 (0.94,1.01)	1.00 (0.96,1.04)	1.02 (0.98,1.05)	0.97 (0.93,1.00)	0.99 (0.96,1.03)
17.7°C (0°F) —	0.88 (0.86,0.91)	0.93 (0.91,0.96)	0.95 (0.93,0.98)	0.99 (0.97,1.02)	0.98 (0.96,1.01)	1.02 (0.99,1.04)	1.01 (0.98,1.04)
−15°C (5°F) —	0.89 (0.87,0.91)	0.96 (0.94,0.97)	0.98 (0.97,1.00)	0.97 (0.95,0.99)	1.00 (0.98,1.02)	1.00 (0.98,1.02)	1.01 (0.99,1.03)
−12.2°C (10°F) —	0.92 (0.91,0.93)	0.94 (0.93,0.95)	0.96 (0.95,0.97)	0.97 (0.95,0.98)	1.00 (0.98,1.01)	0.99 (0.98,1.01)	1.00 (0.98,1.01)
−9.4°C (15°F) —	0.91 (0.90,0.92)	0.95 (0.94,0.97)	0.97 (0.96,0.98)	0.98 (0.97,0.99)	0.97 (0.96,0.98)	0.99 (0.98,1.00)	0.99 (0.98,1.00)
−6.6°C (20°F) —	0.92 (0.91,0.93)	0.96 (0.95,0.97)	0.97 (0.96,0.98)	0.97 (0.96,0.98)	0.98 (0.97,0.99)	0.99 (0.98,1.00)	0.98 (0.97,0.99)
−3.8°C (25°F) —	0.94 (0.93,0.95)	0.98 (0.97,0.99)	0.98 (0.97,0.99)	0.98 (0.98,0.99)	0.99 (0.98,1.00)	0.98 (0.97,0.99)	0.99 (0.98,1.00)
−1.1°C (30°F) —	0.96 (0.95,0.97)	0.98 (0.97,0.99)	0.98 (0.97,0.99)	0.98 (0.97,0.99)	0.98 (0.97,0.99)	0.99 (0.98,1.00)	0.98 (0.97,0.99)
1.6 °C(35°F) —	0.98 (0.97,0.98)	0.99 (0.98,1.00)	0.98 (0.97,0.99)	0.98 (0.97,0.99)	0.99 (0.98,1.00)	0.98 (0.97,0.99)	0.98 (0.97,0.99)
4.4°C (40°F) —	0.98 (0.97,0.99)	1.00 (0.99,1.01)	1.00 (0.99,1.01)	0.99(0.98,1.00)	0.99 (0.98,1.00)	0.99 (0.98,1.00)	0.98 (0.97,0.99)
7.2°C (45°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)

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[*] *OR* = odds ratio;

[†] *CI* =confidence interval.

Note: ORs were adjusted for particulate matter less than 2.5μm.

Table 2

Wind chill Temperature and Air Temperature Effects on Cardiovascular Disease Emergency Department Visits in Transitional Month (November) from 2005 to 2013 in New York State

	Lag 0 OR * (95% CI †)	Lag 1 OR (95% CI)	Lag 2 OR (95% CI)	Lag 3 OR (95% CI)	Lag 4 OR (95% CI)	Lag 5 OR (95% CI)	Lag 6 OR (95% CI)
Wind chill Temperature							
−34.4°C (−30°F) —	0.56 (0.40,0.78)	0.81 (0.60,1.09)	0.93 (0.66,1.33)	1.35 (0.88,2.06)	0.84 (0.53,1.33)	1.03 (0.65,1.64)	–
−31.6°C (−25°F) —	0.88 (0.57,1.34)	0.84 (0.44,1.60)	1.33 (0.80,2.21)	0.81 (0.48,1.36)	1.04 (0.60,1.78)	–	0.87 (0.51,1.47)
−28.8°C (−20°F) —	0.92 (0.80,1.05)	0.84 (0.72,0.98)	0.79 (0.66,0.96)	0.97 (0.81,1.17)	0.85 (0.70,1.05)	1.07 (0.88,1.31)	1.07 (0.87,1.33)
−26.1 °C (−15°F) —	0.87 (0.78,0.96)	0.84 (0.76,0.92)	0.89 (0.80,0.99)	0.89 (0.80,1.00)	1.05 (0.94,1.17)	1.10 (0.99,1.22)	1.09 (0.95,1.23)
−23.3°C (−10°F) —	0.80 (0.74,0.87)	0.88 (0.81,0.96)	0.96 (0.88,1.04)	1.06 (0.98,1.15)	1.04 (0.95,1.13)	1.14 (1.04,1.25)	0.99 (0.91,1.09)
−20.5°C (−5°F) —	0.82 (0.78,0.87)	0.89 (0.84,0.95)	0.98 (0.92,1.04)	1.02 (0.96,1.09)	1.04 (0.97,1.10)	1.02 (0.96,1.09)	0.95 (0.90,1.02)
−17.7°C (0°F) —	0.88 (0.83,0.93)	0.86 (0.81,0.91)	0.92 (0.87,0.98)	0.94 (0.89,1.00)	0.98 (0.92,1.04)	1.11 (1.04,1.18)	1.05 (0.98,1.11)
−15°C (5°F) —	0.92 (0.87,0.97)	0.89 (0.84,0.94)	0.91 (0.86,0.96)	0.99 (0.94,1.04)	1.08 (1.02,1.14)	1.15 (1.09,1.22)	1.09 (1.03,1.16)
−12.2°C (10°F) —	0.86 (0.82,0.90)	0.85 (0.81,0.89)	0.93 (0.88,0.97)	1.05 (1.00,1.10)	1.02 (0.97,1.07)	1.12 (1.06,1.18)	1.04 (0.99,1.10)
−9.4°C (15°F) —	0.92 (0.89,0.96)	0.93 (0.90,0.96)	1.02 (0.98,1.06)	1.01 (0.97,1.05)	1.02 (0.98,1.06)	1.09 (1.05,1.14)	1.02 (0.98,1.06)
−6.6°C (20°F) —	0.98 (0.96,1.01)	0.98 (0.95,1.01)	1.00 (0.98,1.03)	1.04 (1.01,1.07)	1.01 (0.98,1.04)	1.06 (1.02,1.09)	0.96 (0.93,1.00)
−3.8°C (25°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Air temperature							
−12.2°C (10°F) —	0.81 (0.58,1.14)	1.37 (0.87,2.16)	1.13 (0.73,1.76)	1.80 (1.06,3.06)	1.38 (0.83,2.30)	0.92 (0.54,1.58)	0.86 (0.49,1.51)
−9.4°C (15°F) —	0.72 (0.66,0.78)	0.94 (0.87,1.02)	1.02 (0.93,1.12)	0.98 (0.90,1.07)	1.04 (0.96,1.13)	1.15 (1.05,1.26)	1.24 (1.11,1.38)
−6.6°C (20°F) —	0.82 (0.79,0.85)	0.86 (0.82,0.89)	1.00 (0.96,1.04)	1.03 (0.99,1.07)	1.07 (1.03,1.12)	1.11 (1.07,1.16)	1.10 (1.05,1.16)
−3.8°C (25°F) —	0.87 (0.85,0.89)	0.93 (0.91,0.95)	1.00 (0.98,1.02)	1.02 (1.00,1.05)	1.02 (1.00,1.04)	1.08 (1.06,1.11)	1.03 (1.01,1.06)
−1.1°C (30°F) —	0.93 (0.91,0.94)	0.94 (0.93,0.96)	0.97 (0.96,0.99)	1.01 (0.99,1.03)	1.02 (1.00,1.04)	1.02 (1.01,1.04)	1.01 (0.99,1.02)
1.6 °C(35°F) —	0.95 (0.94,0.97)	0.97 (0.95,0.98)	0.99 (0.98,1.01)	1.00 (0.99,1.02)	1.00 (0.99,1.01)	1.02 (1.01,1.03)	1.01 (0.99,1.02)
4.4°C (40°F) —	0.99 (0.98,1.01)	1.01 (1.00,1.02)	1.01 (1.00,1.03)	1.01 (1.00,1.02)	0.99(0.98,1.00)	1.02 (1.00,1.03)	1.01 (0.99,1.02)
7.2°C (45°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)

* *OR* = odds ratio;

† *CI* =confidence interval.

Note: ORs were adjusted for particulate matter less than 2.5µm.

Note: temperatures ranging 10°F to −10°F are not shown due to low number or no cases

"—" represents there were no cases for the particular temperature category and lag period needed to calculate statistical results

Table 3

Wind chill Temperature and Air temperature Effects on Cardiovascular Disease Emergency Department Visits in Transitional Month (March) from 2005 to 2013 in New York State

	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6
	OR * (95% CI†)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Wind chill Temperature							
−34.4°C (−30°F) —	1.02 (0.90,1.15)	0.95 (0.84,1.07)	1.00 (0.90,1.13)	1.04 (0.93,1.16)	1.14 (1.04,1.25)	0.94 (0.86,1.04)	1.08 (0.99,1.18)
−31.6°C (−25°F) —	1.00 (0.91,1.11)	0.96 (0.87,1.06)	0.89 (0.81,0.98)	0.98 (0.89,1.07)	1.08 (0.98,1.18)	1.08 (0.98,1.19)	1.06 (0.97,1.16)
−28.8°C (−20°F) —	0.94 (0.89,1.01)	0.93 (0.87,0.99)	1.01 (0.94,1.08)	1.05 (0.99,1.12)	0.99 (0.93,1.05)	1.01 (0.95,1.07)	1.04 (0.98,1.10)
−26.1 °C (−15°F) —	0.97 (0.92,1.03)	0.93 (0.88,0.98)	1.02 (0.97,1.07)	1.03 (0.98,1.09)	0.99 (0.94,1.04)	0.98 (0.93,1.03)	1.01 (0.96,1.06)
−23.3°C (−10°F) —	0.93 (0.89,0.98)	0.99 (0.95,1.03)	1.00 (0.96,1.04)	1.01 (0.97,1.05)	1.03 (0.99,1.07)	0.97 (0.93,1.01)	1.00 (0.96,1.04)
−20.5°C (−5°F) —	0.94 (0.91,0.98)	0.96 (0.93,1.00)	0.99 (0.96,1.03)	1.03 (0.99,1.06)	1.02 (0.99,1.06)	0.99 (0.96,1.02)	1.01 (0.98,1.05)
−17.7°C (0°F) —	0.98 (0.95,1.01)	0.98 (0.95,1.01)	1.00 (0.98,1.03)	1.00 (0.97,1.03)	1.02 (1.00,1.05)	1.01 (0.99,1.04)	1.02 (0.99,1.04)
−15°C (5°F) —	0.97 (0.94,1.00)	0.98 (0.95,1.01)	0.99 (0.96,1.01)	1.01 (0.98,1.03)	1.00 (0.98,1.02)	1.01 (0.99,1.03)	1.03 (1.00,1.05)
−12.2°C (10°F) —	0.98 (0.96,1.00)	0.99 (0.96,1.01)	1.01 (0.99,1.03)	1.01 (0.99,1.03)	1.00 (0.98,1.02)	0.99 (0.97,1.01)	1.01 (0.99,1.03)
−9.4°C (15°F) —	0.98 (0.96,1.00)	1.00 (0.98,1.02)	1.02 (1.00,1.04)	0.99 (0.98,1.01)	1.00 (0.99,1.02)	0.99 (0.97,1.01)	0.99 (0.98,1.01)
−6.6°C (20°F) —	0.99 (0.98,1.01)	1.00 (0.98,1.02)	1.02 (1.00,1.03)	1.01 (0.99,1.03)	1.00 (0.98,1.01)	1.00 (0.98,1.01)	1.00 (0.99,1.02)
−3.8°C (25°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)
Air temperature							
−23.3°C (−10°F) —	—	—	—	1.29 (0.65,2.54)	1.50 (0.79,2.83)	1.15 (0.71,1.86)	1.19 (0.63,2.27)
−20.5°C (−5°F) —	1.08 (0.66,1.75)	1.15 (0.60,2.18)	0.62 (0.32,1.18)	0.71 (0.37,1.36)	0.82 (0.41,1.64)	0.50 (0.20,1.28)	0.71 (0.32,1.57)
17.7°C (0°F) —	0.87 (0.74,1.03)	0.89 (0.75,1.07)	1.10 (0.94,1.28)	1.03 (0.89,1.19)	1.01 (0.89,1.15)	1.02 (0.89,1.17)	0.97 (0.85,1.10)
−15°C (5°F) —	0.89 (0.81,0.96)	0.91 (0.84,0.98)	0.98 (0.92,1.05)	1.05 (0.99,1.10)	1.01 (0.96,1.07)	0.98 (0.93,1.04)	1.06 (1.01,1.12)
−12.2°C (10°F) —	0.94 (0.90,0.97)	0.97 (0.94,1.01)	1.02 (0.99,1.05)	1.05 (1.01,1.08)	1.06 (1.02,1.09)	1.06 (1.03,1.09)	1.05 (1.01,1.08)
−9.4°C (15°F) —	0.96 (0.93,0.98)	0.97 (0.94,0.99)	0.98 (0.96,1.01)	1.00 (0.98,1.03)	1.03 (1.01,1.05)	1.05 (1.02,1.07)	1.04 (1.01,1.06)
−6.6°C (20°F) —	0.98 (0.96,0.99)	0.99 (0.98,1.01)	1.01 (0.99,1.03)	1.00 (0.98,1.01)	1.01 (0.99,1.03)	1.03 (1.01,1.05)	1.02 (1.00,1.04)
−3.8°C (25°F) —	0.97 (0.96,0.99)	0.99 (0.98,1.01)	1.01 (0.99,1.03)	1.01 (0.99,1.02)	1.00 (0.99,1.02)	1.02 (1.00,1.03)	1.01 (1.00,1.03)
−1.1°C (30°F) —	0.98 (0.97,0.99)	0.99 (0.98,1.01)	1.00 (0.98,1.01)	1.00 (0.98,1.01)	1.01 (1.00,1.03)	1.03 (1.01,1.04)	1.00 (0.99,1.02)
1.6 °C(35°F) —	0.99 (0.98,1.00)	1.00 (0.98,1.01)	1.00 (0.98,1.01)	0.99 (0.98,1.00)	1.01 (1.00,1.02)	1.02 (1.01,1.04)	1.01 (0.99,1.02)
4.4°C (40°F) —	0.99 (0.98,1.01)	0.98 (0.97,1.00)	0.99 (0.98,1.01)	0.98 (0.97,0.99)	1.00 (0.99,1.01)	1.02 (1.00,1.03)	1.00 (0.99,1.01)
7.2°C (45°F) —	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)	1.00 (Referent)

[*] *OR* = odds ratio;

[†] *CI* =confidence interval.

Note: ORs were adjusted for particulate matter less than 2.5µm

"—" represents there were no cases for the particular temperature category and lag period needed to calculate statistical results "

Table 4

Wind chill Temperature and Air Temperature Effects by Cardiovascular Disease Subtypes in Lag 5 from November to March, 2005 – 2013, New York State

	Hypertension OR * (95% CI †)	IHD OR * (95% CI †)	Dysrhythmias OR * (95% CI †)	CD OR * (95% CI †)	Other CVD ‡ OR * (95% CI †)
Wind Chill					
−34.4°C (−30°F) —	1.55 (0.46,5.22)	0.78 (0.31,1.95)	0.28 (0.07,1.23)	2.40 (0.15,39.00)	1.44 (0.26,8.01)
−31.6°C (−25°F) —	0.96 (0.53,1.75)	0.71 (0.36,1.42)	0.85 (0.50,1.45)	0.63 (0.07,5.99)	1.33 (0.56,3.18)
−28.8°C (−20°F) —	1.38 (1.03,1.83)	0.96 (0.70,1.32)	0.82 (0.59,1.13)	0.97 (0.53,1.79)	1.33 (0.87,2.05)
−26.1 °C (−15°F) —	1.07 (0.93,1.23)	1.18 (1.02,1.38)	0.95 (0.82,1.09)	0.94(0.70,1.25)	0.95 (0.76,1.19)
−23.3°C (−10°F) —	1.07 (0.98,1.16)	1.08 (0.99,1.18)	1.07 (0.98,1.16)	1.05 (0.88,1.25)	0.99 (0.86,1.14)
−20.5°C (−5°F) —	1.09 (1.03,1.15)	0.97 (0.91,1.03)	0.97 (0.91,1.02)	1.03 (0.92,1.15)	1.06 (0.96,1.16)
−17.7°C (0°F) —	1.07 (1.03,1.10)	1.06 (1.01,1.10)	1.00 (0.96,1.05)	0.98 (0.91,1.06)	1.05 (0.99,1.13)
−15°C (5°F) —	1.03 (1.00,1.05)	1.03 (0.99,1.06)	1.03 (0.99,1.06)	0.97 (0.92,1.03)	1.02 (0.97,1.08)
−12.2°C (10°F) —	1.07 (1.05,1.09)	1.01 (0.99,1.04)	1.01 (0.98,1.04)	1.02 (0.97,1.07)	1.02 (0.97,1.06)
−9.4°C (15°F) —	1.02 (1.01,1.04)	1.02 (0.99,1.04)	1.01 (0.99,1.04)	0.98 (0.94,1.02)	0.98 (0.94,1.02)
−6.6°C (20°F) —	1.05 (1.03,1.06)	1.03 (1.01,1.05)	1.02 (1.00,1.04)	1.02 (0.98,1.06)	1.05 (1.01,1.09)
−3.8°C (25°F) —	1.00(Referent)	1.00(Referent)	1.00(Referent)	1.00(Referent)	1.00(Referent)
Air Temperature					
−23.3°C (−10°F) —	1.06 (0.59,1.89)	1.32 (0.69,2.52)	0.62 (0.32,1.23)	1.13 (0.31,4.20)	1.13 (0.45,2.85)
−20.5°C (−5°F) —	1.10 (0.72,1.69)	0.63 (0.40,1.00)	0.72 (0.48,1.08)	0.63 (0.21,1.83)	1.13 (0.66,1.95)
17.7°C (0°F) —	1.18 (1.00,1.40)	1.22 (1.02,1.45)	0.98 (0.83,1.16)	1.29 (0.93,1.79)	0.97 (0.74,1.28)
−15°C (5°F) —	1.06 (0.97,1.16)	1.05 (0.95,1.16)	1.03 (0.94,1.13)	0.82 (0.68,0.99)	0.88 (0.75,1.03)
−12.2°C (10°F) —	1.06 (1.00,1.12)	1.06 (1.00,1.13)	0.96 (0.90,1.02)	1.02 (0.91,1.14)	1.01 (0.91,1.11)
−9.4°C (15°F) —	1.04 (1.01,1.08)	1.00 (0.96,1.05)	0.99 (0.95,1.03)	0.93 (0.86,1.00)	1.06 (1.00,1.13)
−6.6°C (20°F) —	1.03 (1.01,1.05)	1.00 (0.97,1.03)	1.01 (0.98,1.04)	0.94 (0.90,0.99)	1.03 (0.99,1.08)
−3.8°C (25°F) —	1.03 (1.02,1.05)	1.02 (0.99,1.04)	1.00 (0.97,1.02)	0.99 (0.95,1.04)	1.01 (0.97,1.05)
−1.1°C (30°F) —	1.00 (0.99,1.01)	0.98 (0.96,1.01)	0.97 (0.95,1.00)	0.97 (0.94,1.01)	1.01 (0.98,1.05)
1.6 °C(35°F) —	0.99 (0.98,1.01)	0.98 (0.96,1.00)	1.00 (0.98,1.02)	0.98 (0.95,1.01)	1.02 (0.99,1.05)
4.4°C (40°F) —	0.98 (0.97,0.99)	0.98 (0.97,1.00)	0.99 (0.97,1.01)	0.95 (0.93,0.98)	1.00 (0.97,1.03)
7.2°C (45°F) —	1.00(Referent)	1.00(Referent)	1.00(Referent)	1.00(Referent)	1.00(Referent)

Abbreviations: IHD: ischemic heart disease; CD: cerebrovascular diseases;

* *OR* = odds ratio;

† *CI* =confidence interval.

‡ Other CVD: Acute myocardial infarction, Chronic rheumatic heart disease, and congestive heart failure

Note: Odds Ratios were adjusted for particulate matter less than 2.5μm

"—" represents there were no cases for the particular temperature category and lag period needed to calculate statistical results