

# Seasonality and Daily Weather Conditions in Relation to Myocardial Infarction and Sudden Cardiac Death in Olmsted County, Minnesota, 1979 to 2002

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<b>OBJECTIVES</b>	We assessed the relationship of season and weather types with myocardial infarction (MI) and sudden cardiac death (SCD) in a geographically defined population, and tested the hypothesis that the increased risk in winter was related to weather.
<b>BACKGROUND</b>	Winter peaks in coronary heart disease (CHD) have been documented. Yet, it is uncertain if seasonality exists for both incident events and deaths, and the role of weather conditions is not clear.
<b>METHODS</b>	The daily occurrence of incident MI and SCD in Olmsted County was examined with data from the National Weather Service. Poisson regression models were used to assess the relative risks (RRs) associated with season and climatic variables. Subsequent analysis stratified SCD into those with and without antecedent CHD (unexpected SCD).
<b>RESULTS</b>	Between 1979 and 2002, 2,676 MI and 2,066 SCD occurred. The age-, gender-, and year-adjusted RR of SCD, but not of MI, was increased in winter versus summer (1.17, 95% confidence interval [CI] 1.03 to 1.32) and in low temperatures (1.20, 95% CI 1.07 to 1.35, for temperatures below 0°C vs. 18°C to 30°C). These associations were stronger for unexpected SCD than for SCD with prior CHD ( $p < 0.05$ ). After adjustment for all climatic variables, low temperature was associated with a large increase in the risk of unexpected SCD (RR = 1.38, 95% CI 1.10 to 1.73), while the association with winter declined (RR = 1.06, 95% CI 0.83 to 1.35).
<b>CONCLUSIONS</b>	These data suggest that the winter peak in SCD can be accounted for by daily weather. (J Am Coll Cardiol 2006;48:287–92) © 2006 by the American College of Cardiology Foundation

Seasonality in coronary heart disease (CHD) events, with a winter peak and summer nadir, has been recognized for many decades and across diverse populations (1–14). Yet, the extent to which this variation reflects weather effects remains uncertain, as weather data were not available in most studies. Among the studies involving daily weather, many were limited in their outcome measures to either deaths (6,15–19) or hospital admissions (20,21) rather than CHD incidence, while others did not include persons over 64 years (21–24), the age past which most CHD events occur (25,26). The inclusion of all age groups is essential in this context because climatic variables have been suggested to correlate more strongly with CHD risk as age increases (5,6,8,11,17). Further, it is unknown if the possible effects of season and weather apply equally to incident events and deaths (22–24), and whether the association with deaths varies among persons with and without prior CHD (7,22,23).

In this community-based surveillance study, we examined the relationship of season, daily temperature, and precipitation with CHD events over 24 years in an area known for its wide range of temperatures throughout the year and extreme cold during late fall and winter. Specifically, we evaluated the association of climatic variables with incident myocardial infarction (MI) and sudden cardiac death (SCD), assessed differences in the relationship between climatic variables and SCD according to prior CHD status, and tested whether the seasonal variation was accounted for by daily weather conditions.

## METHODS

**Study setting.** The population of Olmsted County is served by a largely unified medical care system that has accumulated comprehensive clinical records over an extensive period (27). Olmsted County (2000 census population, 124,277) is 144 km southeast of Minneapolis and St. Paul, with approximately 70% of its population residing in Rochester, the centrally located county seat. In 2000, about 90% of all residents were white and 11% were aged 65 years or older. With the exception of a higher proportion being employed in the health care industry, the population characteristics are similar to those of U.S. whites.

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Manuscript received January 12, 2006; revised manuscript received February 9, 2006, accepted February 14, 2006.

#### Abbreviations and Acronyms

CHD	= coronary heart disease
CI	= confidence interval
ICD	= International Classification of Diseases
MI	= myocardial infarction
RR	= relative risk
SCD	= sudden cardiac death

Olmsted County is relatively isolated from other urban centers, and nearly all medical care is delivered to local residents by a handful of providers. The Mayo Medical Center and the Olmsted Medical Center and its affiliated hospital provide comprehensive care for the region in every clinical discipline. The epidemiologic potential of this situation is enhanced by the fact that each provider uses a unit medical record system, whereby all data collected for an individual are assembled in one place. The Mayo Clinic unit record, for example, contains the details of every inpatient hospitalization at its 2 affiliated hospitals, every outpatient visit to a physician's office or to the emergency department, every physician visit to nursing homes or private homes, and every laboratory result, all pathology reports, and all correspondence concerning each patient. The unit records of each provider in the county are available for use. These medical records are easily retrievable because the Mayo Clinic has maintained since the early 1900s extensive indexes based on clinical and histologic diagnoses and surgical and billable procedures. The Rochester Epidemiology Project (27) has developed a similar index for the records of other providers of medical care to local residents. The result is the linkage of medical records from essentially all sources of medical care available to and used by the Olmsted County population. All aspects of the study were approved by the appropriate institutional review boards.

**Weather types and seasons.** Climatic data were obtained from the National Weather Service and included hourly readings and daily summaries made at the Rochester Municipal Airport (approximately 9 km south of Rochester) for the entire study period. These data were used to classify each day according to the occurrence (yes/no) of 3 rain categories (including rainfall and melted frozen precipitation), defined as: 1) heavy rain ( $\geq 0.25$  cm); 2) mild rain ( $0.025$  to  $<0.25$  cm); and 3) no rain ( $<0.025$  cm; reference category); 3 snow categories (including snowfall and sleet/ice pellets), defined as: 1) heavy snow ( $\geq 2.5$  cm); 2) mild snow ( $0.25$  to  $<2.5$  cm); and 3) no snow ( $<0.25$  cm; reference category); and 4 temperature categories (based on maximum daily temperature), defined as: 1)  $>30^{\circ}\text{C}$  ( $>86^{\circ}\text{F}$ ); 2)  $18$  to  $30^{\circ}\text{C}$  ( $64^{\circ}\text{F}$  to  $86^{\circ}\text{F}$ ; reference category); 3)  $0$  to  $17^{\circ}\text{C}$  ( $32^{\circ}\text{F}$  to  $63^{\circ}\text{F}$ ); and 4)  $<0^{\circ}\text{C}$  ( $<32^{\circ}\text{F}$ ). Daily summaries were used for all analyses as the outcome data were recorded daily (28).

Seasons were classified as fall (September 21 through December 20), winter (December 21 through March 21),

spring (March 22 through June 21), and summer (June 22 through September 20; reference category).

**Outcome measures. INCIDENT MI.** The methods used to ascertain the incidence of MI relied on standardized epidemiologic criteria and have been previously published (26,29). Briefly, Olmsted County residents with diagnoses compatible with MI were identified from the Rochester Epidemiology Project indexes, reviewed by trained abstractors, and validated using data on cardiac pain, elevated biomarker values, and electrocardiography. For incident status verification, the full medical record of each candidate case was searched for any episode compatible with previous infarction. Patients with prior MI were excluded.

**SCD.** Sudden cardiac death ascertainment relied on standardized criteria based on death certificates (29-31), which since the late 1960s contain the location of death as coded by the Minnesota Department of Health. Cardiac deaths were classified as sudden if they occurred out of the hospital and were assigned codes 410 to 414 of the International Classification of Diseases-Ninth Revision (ICD-9), or I20 to I25 of the ICD-Tenth Revision (ICD-10) (32). We defined out-of-hospital deaths as those taking place outside of acute-care or long-term-care hospitals, including deaths occurring in emergency departments, private homes, public places, nursing or boarding-care homes, and infirmaries, as well as deaths among persons declared dead on arrival at a hospital.

Prior CHD was ascertained from the entire community medical record and considered present if any of the following criteria were met: 1) acute MI; 2) coronary artery bypass graft or percutaneous transluminal coronary angioplasty; or 3) angiographic coronary disease, as defined by a standard algorithm (33).

The record linkage system in place under the auspices of the Rochester Epidemiology Project ensures complete capture of all components of this definition when occurring in the county.

**Statistical analyses.** Age-, gender-, and year-specific event rates were calculated for each season, weather, and precipitation category. The denominators were derived from Olmsted County population census data for 1970, 1980, 1990 and 2000, with linear interpolation for the intercensal years and extrapolation after 2000 (34). These rates were directly standardized to the age and gender distribution of the 2000 U.S. population.

Poisson regression models were used to assess the relative risks (RRs) and 95% confidence intervals (CIs) of incident MI and SCD associated with season and daily weather variables. The logarithm of the counts was modeled with the logarithm of the year-, age-, and gender-specific population size as the offset using the SAS GENMOD procedure. Two-way interaction terms were used to test for effect modification by outcome type, prior CHD status, age, gender, and calendar year.

**Table 1.** Daily Weather Summaries by Season in Olmsted County, Minnesota, 1979 to 2002

Season	Maximum Daily Temperature			Precipitation*			
	Mean (SD)	>30°C	<0°C	Heavy Rain	Mild Rain	Heavy Snow	Mild Snow
Summer	26 (4)	13%	0%	21%	10%	0%	0%
Fall	8 (9)	0%	20%	13%	12%	5%	9%
Winter	-3 (7)	0%	59%	9%	15%	11%	17%
Spring	17 (8)	4%	1%	21%	13%	2%	3%

\*Precipitation categories are defined as follows (values represent daily amount in cm): heavy rain  $\geq 0.25$ ; mild rain 0.025 to <0.25; heavy snow  $\geq 2.5$ ; mild snow 0.25 to <2.5.

A p value of 0.05 was selected for the threshold of statistical significance. Analyses were performed using SAS version 8.2 (SAS Institute, Cary, North Carolina).

**RESULTS**

From January 1, 1979 through December 31, 2002, 2,066 SCD (48% women) and 2,676 incident MI (43% women) were recorded in Olmsted County. The mean age (SD) was 78 (13) years at SCD and 68 (14) years at incident MI (p < 0.001). Among all SCD, 65% had no evidence of prior CHD (i.e., unexpected SCD).

Over the study period (8,766 days), the average maximum daily temperature was 12°C, ranging from -29°C to 39°C. Rain was recorded in 29% (13% mild rain; 16% heavy rain) and snow in 12% (7% mild snow; 5% heavy snow) of the days. The mean summer temperature was 26°C, compared with a winter average of -3°C. In addition, a higher frequency of rainy days was found during summer and spring, whereas snow occurred mainly during fall and winter (Table 1).

**Seasonality in CHD events.** A seasonal pattern was observed in SCD, as the standardized rates were highest in the winter and lowest in the summer. Correspondingly, the age-, gender-, and year-adjusted RR were 1.12 (95% CI 0.99 to 1.27) in the fall, 1.17 (95% CI 1.03 to 1.32) in the winter, and 1.09 (95% CI 0.97 to 1.24) in the spring, compared with the summer. For incident MI, no seasonal variation was detected, as the standardized rates and the adjusted RR were quite similar across seasons (Table 2).

In an analysis stratifying SCD according to prior CHD status (Fig. 1), a significant association with fall (RR = 1.19, 95% CI 1.01 to 1.39) and winter (RR = 1.28, 95% CI 1.10 to 1.50) was observed for unexpected SCD, while no association was shown for SCD with prior CHD (RR = 0.99, 95% CI 0.80 to 1.22, for fall; and RR = 0.98, 95% CI 0.79 to 1.20, for winter) (p = 0.04 for the winter-by-prior CHD interaction).

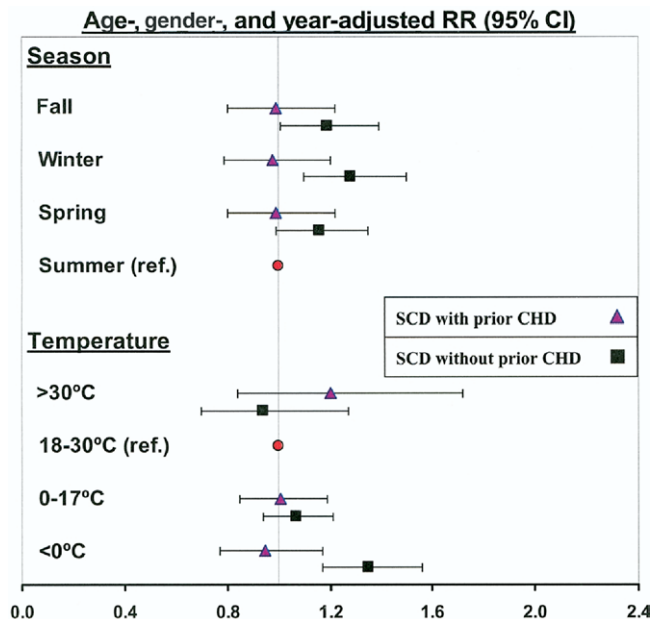
**Temperature and CHD events.** Cold temperatures were associated with an increased risk of SCD, but not with incident MI. The standardized rates of SCD peaked in days with maximum temperature below 0°C and, correspond-

**Table 2.** Standardized Rates and RRs (95% CI) of MI and SCD for Seasonal and Climatic Variables

	Days	Incident MI		SCD	
		Rate*	RR (95% CI)†	Rate*	RR (95% CI)†
<b>Season</b>					
Fall	2,184	5.18	1.02 (0.92-1.14)	4.10	1.12 (0.99-1.27)
Winter	2,190	5.32	1.04 (0.94-1.16)	4.26	1.17 (1.03-1.32)
Spring	2,208	5.36	1.06 (0.95-1.17)	3.99	1.09 (0.97-1.24)
Summer	2,184	5.06	1 (reference)	3.66	1 (reference)
<b>Temperature</b>					
>30°C	362	4.98	0.93 (0.76-1.14)	3.67	1.02 (0.81-1.29)
18°C-30°C	3,220	5.21	1 (reference)	3.83	1 (reference)
0°C-17°C	3,422	5.18	0.97 (0.89-1.06)	3.92	1.05 (0.95-1.16)
<0°C	1,762	5.43	1.03 (0.92-1.14)	4.54	1.20 (1.07-1.35)
<b>Rain‡</b>					
Heavy rain	1,421	5.00	0.94 (0.85-1.05)	3.92	0.97 (0.86-1.09)
Mild rain	1,100	5.25	0.99 (0.88-1.11)	3.87	0.95 (0.83-1.09)
No rain	6,245	5.28	1 (reference)	4.04	1 (reference)
<b>Snow‡</b>					
Heavy snow	384	5.37	1.02 (0.85-1.23)	4.07	1.00 (0.81-1.24)
Mild snow	633	5.47	1.04 (0.90-1.20)	4.28	1.06 (0.90-1.25)
No snow	7,749	5.20	1 (reference)	3.98	1 (reference)

\*Rates per 10<sup>6</sup> person-days are directly standardized to the age and gender distribution of the 2000 U.S. population; †the relative risks (95% confidence intervals [CI]) are derived from Poisson regression models adjusting for age, gender, year, and all other variables within each season or weather group; ‡rain and snow categories are defined as follows (values represent daily amount in cm): heavy rain  $\geq 0.25$ ; mild rain 0.025 to <0.25; heavy snow  $\geq 2.5$ ; mild snow 0.25 to <2.5.

MI = myocardial infarction; RR = relative risk; SCD = sudden cardiac death.



**Figure 1.** Association of season and temperature with sudden cardiac death (SCD) stratified by prior coronary heart disease (CHD) status. The relative risks (RRs) (95% confidence intervals [CIs]) are derived from Poisson regression models adjusting for age, gender, year, and all other variables within each season or temperature group.

ingly, the age-, gender-, and year-adjusted RR was 1.20 (95% CI 1.07 to 1.35), compared with the reference category (18°C to 30°C). No such association was seen for MI (Table 2).

Furthermore, an effect modification by prior CHD status was found in the relationship between temperature and SCD, as the RR associated with temperature below 0°C was 1.35 (95% CI 1.17 to 1.56) for unexpected SCD and 0.95 (95% CI 0.77 to 1.17) for SCD with prior CHD, compared with the 18°C to 30°C category (p = 0.004 for the interaction) (Fig. 1).

**Precipitation and CHD events.** Neither rain nor snow was significantly related to either outcome. For incident MI, the age-, gender-, and year-adjusted RR was 0.99 (95% CI 0.88 to 1.11) for mild rain and 0.94 (95% CI 0.85 to 1.05) for heavy rain, as well as 1.04 (95% CI 0.90 to 1.20) for mild snow and 1.02 (95% CI 0.85 to 1.23) for heavy snow. For SCD, the adjusted RR was 0.95 (95% CI 0.83 to 1.09) for mild rain and 0.97 (95% CI 0.86 to 1.09) for heavy rain, as well as 1.06 (95% CI 0.90 to 1.25) for mild snow and 1.00 (95% CI 0.81 to 1.24) for heavy snow (Table 2).

**Season, temperature, and precipitation in relation to CHD events.** In a regression model adjusting for age, gender, year, and all season and climatic variables, temperature below 0°C was strongly associated with unexpected SCD (RR = 1.38, 95% CI 1.10 to 1.73), whereas the RR associated with fall and winter declined substantially (1.09, 95% CI 0.88 to 1.34; and 1.06, 95% CI 0.83 to 1.35, respectively). In contrast, no associations were noticed between season or climatic variables and either incident MI or SCD with prior CHD.

In an examination of all possible exposure-outcome interactions by calendar year, age, and gender, no interaction was significant except for an effect modification by gender in the relationship between heavy snow and SCD (RR = 1.30, 95% CI 1.00 to 1.69, for men; RR = 0.69, 95% CI 0.48 to 0.99, for women, p = 0.005 for the interaction). The gender-snow interaction was not attenuated after adjustment for age, year, season, temperature, and rain.

**DISCUSSION**

A winter increase in CHD events has been noted for many years (14) and in diverse locations, including Canada (8), Minnesota (16), California (4), Great Britain (6,7,13), Germany (5), Russia (18), Israel (35), Kuwait (36), India (37), and Australia (10,22). However, the extent to which these variations reflect the possible short-term effects of weather conditions, such as temperature, rainfall, and snowfall, remains unclear, because much of the existing literature is limited to seasonal or month-to-month comparisons (1-5,7,8,10,12). When data on daily weather were examined, the outcome measures were often restricted to deaths or hospital admissions (6,15-21), which are subject to misclassification and/or referral biases (38). Few studies were able to combine information on daily weather with validated data on incidence (21-24). Furthermore, these studies were carried out in selected populations, such as young women or middle-aged men, so that the generalizability of their results is uncertain.

In the present study, we used a community surveillance approach to longitudinally evaluate the relationship of season and daily weather conditions with rigorously ascertained MI and SCD (26,29,30). Our results indicate a seasonal variation for SCD, but not for incident MI, characterized by a winter peak and summer trough. This pattern was more pronounced for unexpected SCD than for SCD with prior CHD. The excess winter risk of SCD was largely accounted for by daily weather, particularly low temperature.

Previous studies were inconsistent in their findings as to whether the risk associated with cold weather applies equally to non-fatal and fatal events, with some (22,23,39), though not all (24), reporting a stronger association for mortality than for morbidity. The present data indicate an increase in the risk of SCD, but not of incident MI, associated with low temperature. Further, a recent study has suggested a seasonal variation in the size of myocardial infarcts (as assessed enzymatically), with smaller infarcts occurring during summer months (40). Based on these findings, it is possible that cold stress has more to do with the severity of an event than with its occurrence.

Conflicting evidence has also been reported on the role of antecedent CHD in the relationship between weather and outcome. While some evidence exists for a higher winter vulnerability for MI patients (7), others have failed to detect any modification by prior CHD status (22,23). The present

data support the latter studies and extend their findings by indicating that, if any, a stronger association between low temperature and SCD exists among people without a history of CHD. This finding may reflect a greater actual exposure to cold weather among apparently healthy individuals, whereas coronary patients might have been advised to avoid outdoor cold stress.

A previous study involving data from various European regions (19) has found a greater increase in mortality associated with fall in temperature in areas with mild winters. On the other hand, in Yekaterinburg, Russia, a region with a mean winter temperature of  $-7^{\circ}\text{C}$ , a progressive increase in mortality was observed when the mean daily temperature dropped below  $0^{\circ}\text{C}$  (18). The present study, conducted in a region with comparable climate, supports the latter finding by showing an increase in the risk of SCD only for temperatures below  $0^{\circ}\text{C}$ . This might indicate that cardiac risk is more strongly associated with relative than with absolute changes in temperature.

Data from the U.S. have demonstrated that the seasonal variation in CHD mortality did not attenuate throughout the 1970s and 1980s (1). This finding can be supported and extended by the present study, which indicates that in Olmsted County, not only was seasonal variation in SCD rates stable over the past 24 years, but also the association with low temperatures has not appreciably changed over that period.

Age and gender interactions in the association between season or weather and CHD have been reported in several (5,6,8,17,23), but not all (9,12,18,19), studies. No such variations were noticed in our community-based study, except for a higher risk associated with heavy snow in men than in women. Increased CHD mortality after snowfall or a blizzard has been previously documented in both Massachusetts (41) and Minneapolis-St. Paul (16). A possible explanation for the gender difference in our study may involve the acute exertion of snow shoveling shortly after a snowfall (18).

Several biological mechanisms may be involved in the association between cold weather and SCD. Low temperature has a hazardous effect on blood pressure (42-45), and may alter the ratio of myocardial oxygen supply to demand, increase ventricular wall stress, cardiac work and oxygen requirements, and reduce mechanical efficiency and coronary blood flow (46). Further, cold stress is associated with increases in hematocrit (47), blood viscosity (43), platelet and red blood cell counts (42,43), and fibrinogen, factor VII clotting activity, and C-reactive protein (48).

The present study has several potential limitations. The reliance on death certificates for SCD may introduce bias. Yet, a validation study conducted in Olmsted County has demonstrated a high accuracy of death certificate data for out-of-hospital CHD death (our definition of SCD) throughout the 1980s and 1990s (30). Secondly, while specific weather conditions were measured and analyzed, the actual outdoor exposure to these conditions in the popula-

tion is unknown. It could be assumed that the "real" associations, at the individual level, are stronger than those reported. However, the associations may be due to some other unmeasured confounders. Finally, we could not incorporate data on atmospheric pressure, which was suggested to confer additional information over temperature (24).

**Conclusions.** In this community-based study carried out over a long period of time in a region with unique weather conditions, an increase in the risk of SCD, but not of incident MI, was found in the winter. This excess risk was largely attributable to daily weather, particularly low temperature. The association between cold weather and SCD did not change over time, was similar across age and gender groups, and was stronger for individuals without a history of CHD. Further research is needed to elucidate the biological and non-biological mechanisms by which cold temperature is associated with SCD among apparently healthy individuals.

#### Acknowledgments

The authors are indebted to Susan Stotz, RN, and Ellen E. Koepsell, RN, for their valuable assistance in data collection and study coordination.

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