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Weather warnings predict fall-related injuries among older adults

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Abstract

Background: weather predictions are a useful tool for informing public health planning and prevention strategies for non-injury health outcomes, but the association between winter weather warnings and fall-related injuries has not been assessed previously.
Objective: to examine the association between fall-related injuries among older adults and government-issued winter weather warnings.
Methods: using a dynamic cohort of individuals ≥65 years of age who lived in Montreal between 1998 and 2006, we identified all fall-related injuries from administrative data using a validated set of diagnostic and procedure codes. We compared rates of injuries on days with freezing rain or snowstorm warnings to rates observed on days without warnings. We also compared the incidence of injuries on winter days to non-winter days. All analyses were performed overall and stratified by age and sex.
Results: freezing rain alerts were associated with an increase in fall-related injuries (incidence rate ratio [IRR] = 1.20, 95% confidence interval [CI]: 1.08–1.32), particularly among males (IRR = 1.31, 95% CI: 1.10–1.56), and lower rates of injuries

were associated with snowstorm alerts (IRR = 0.89, 95% CI: 0.80–0.99). The rate of fall-related injuries did not differ seasonally (IRR = 1.00, 95% CI: 0.97–1.03).
Conclusions: official weather warnings are predictive of increases in fall-related injuries among older adults. Public health agencies should consider using these warnings to trigger initiation of injury prevention strategies in advance of inclement weather.

Keywords: *accidental falls, aged, epidemiology, incidence, weather, older people*

Introduction

Falls and fall-related injuries among older adults are a significant and growing public health concern [1]. Thirty per cent of non-institutionalised seniors experience at least one fall every year, and nearly one-quarter of falls result in serious injuries including fractures, joint dislocations, lacerations and severe head injuries [2]. These injuries can lead to chronic pain, a loss of functionality, an increased likelihood of requiring institutionalised care and death [1, 3, 4]. Falls are also responsible for over 85% of all injury-related hospitalisations among older adults [2, 5], and the resulting economic burden from these hospitalisations is profound: in Canada, the average cost of a fall-related injury exceeds $11,000 per emergency department visit and $29,000 per hospitalisation [6]. Similar figures have been reported elsewhere [7, 8]. As the populations of industrialised nations age [9], the burden of fall-related injuries and their associated healthcare costs will increase. Epidemiological research on fall-related injuries is therefore essential for formulating effective prevention strategies that target specific risk factors.

Roughly half of all falls among older adults occur outdoors [10, 11]. While it is generally believed that fall-related injuries are associated with seasonality and adverse weather events, particularly in areas with harsh winter temperatures, research to date has been conflicting. Studies of the relationship between seasonality and fall-related injuries [12–14] and seasonality and hip fractures [15–26] have produced mixed results across various latitudes. Significant increases of injury rates have also been associated with adverse weather conditions [14, 25, 27, 28], but less is known of the change in injury rates after official weather warnings have been publicly issued for inclement weather. Existing research is limited to one study from Scotland, which found a 40% increase in fractures presenting to emergency departments and minor injury units when icy road warnings were issued [29]. However, weather warnings that are issued for inclement weather and that are known to be predictive of health outcomes are a useful tool for public health officials to initiate timely prevention strategies [30]. For fall-related injuries, these strategies could include encouraging environmental modifications or encouraging behavioural modifications for those most at risk.

The aim of this research is to estimate the extent to which wintertime severe freezing rain and snowstorm events, as indicated by official weather warnings issued publicly by government meteorologists, are associated with an increase in fall-related injuries among older adults residing in the Montreal census metropolitan area (CMA) from 1998 to 2006. In addition, we sought to quantify seasonal differences in the rate of fall-related injuries.

Methods

Study population

We used a 19% random sample of all residents of the Montreal CMA, in Quebec, Canada from 1 January 1998 to 31 December 2006. From this open cohort, we included in our study population all individuals who were aged 65 or older at any point during the study period (n = 136,323).

Identification of fall-related injuries

For all individuals in the cohort, we obtained a complete record of their healthcare utilisation data for the 9-year study period from population-based health administrative data sources. From these data, all fall-related injuries were identified using a validated set of diagnostic and procedure codes for fractures, subluxations and lacerations for patients who presented to an emergency department [31]. For each patient experiencing an injury, all codes occurring within 14 days following the event were considered to be one injury to increase the accuracy of the injury definition. The date of the emergency department presentation was used as a proxy for the date of injury.

Meteorological variables

Meteorological data over the study period were obtained from the National Climate Data and Information Archive [32]. Using these data, we defined the winter season based on Natural Resources Canada's definitions of snow cover [33]: for each calendar year, onset of the winter season was defined as the first of 14 or more consecutive days where snow cover was ≥2 cm in depth. The end of the winter season was defined as the last of 14 consecutive days with snow cover ≥2 cm in depth. We also obtained historical records of publicly issued weather warnings for the Montreal CMA from Environment Canada [34]. To meet our study objectives, we included alerts for freezing rain (including freezing drizzle) and alerts for snowstorms (including heavy snowfalls, snow squalls, blowing snow, blizzards and snow storms, combined) in the analyses.

Data analysis

The incidence rates of fall-related injuries were determined by dividing the total number of age- and sex-specific injury events by the total population at risk of injury. Denominator estimates for each age and sex strata were derived by identifying the total number of individuals in the cohort at the start of each month of our study period and using linear interpolation to identify daily estimates. All rates were calculated per 100,000 person-days.

We determined the association between winter weather warnings and fall-related injuries by calculating incidence rate ratios (IRRs) from contingency tables. Restricting our data to only days in the winter season, we examined the rate of injuries on days where a weather warning for freezing rain was issued, compared with the rate on days where no alert was issued. This analysis was then repeated for days where a weather warning for a snowstorm was issued. The seasonal variation of fall-related injuries was also assessed, by comparing the rate of injury on days during the winter season to the rate of injury on all other days of the year.

Several sensitivity analyses were performed. To enable comparisons of our results with prior research and to examine the robustness of our results, we repeated all analyses using a subset of diagnostic and procedure codes specific to hip fractures, as well as for all fall-related injuries excluding hip fractures. We also determined the extent to which injury rates remained elevated following inclement weather alerts by calculating the IRR of fall-related injuries for each day following weather warnings, compared with all days in the winter.

For all rates and IRRs, we calculated corresponding 95% confidence intervals using the exact method [35]. Complete details of the methodology can be found in the Supplementary data, Appendix S1 available in *Age and Ageing* online.

Results

Over the 9-year study period, the incidence rate of fall-related injuries in the Montreal CMA was 8.56 (95% CI: 8.44–8.68) per 100,000 person-days (Table 1). Incidence rates were higher among women than men (IRR = 1.42, 95% CI: 1.38–1.46; Supplementary data, Appendix S2 available in *Age and Ageing* online), and rates were higher among individuals aged 75 and over than among individuals aged 65–74. Figure 1 illustrates the time series of fall-related injury rates in the Montreal CMA for the study period.

Seven hundred and eighty-eight (24.0%) of the 3,287 days in the study period were included in the defined winter season. Six hundred and seventy-three (85.4%) of these days had a mean daily temperature below 0° Celsius. Furthermore, 47 freezing rain warnings and 53 snowstorm warnings occurred during the winter seasons in the study period and were included in analyses.

On days when an alert for hazardous freezing rain was announced in the winter season, there was a 20% increase in all fall-related injuries among older adults (IRR = 1.20, 95% CI: 1.08–1.33) (Table 2). This increase was most noticeable for males at 31% (IRR = 1.31, 95% CI: 1.10–1.56). On days in the winter with a hazardous snowstorm alert, a 11% decrease in fall-related injuries was observed (IRR = 0.89, 95% CI: 0.80–0.99). However, the decrease was not statistically significant in any age- or sex-specific stratum. Furthermore, no seasonal difference in fall-related injuries was observed (IRR = 1.01, 95% CI: 0.98–1.04; Supplementary data, Appendix S2 available in *Age and Ageing* online).

In sensitivity analyses, neither freezing rain warnings nor snowstorm warnings were associated with a statistically significant difference in hip fracture rates, for any age–sex stratum (Table 2). These injuries, however, displayed a seasonal pattern (Supplementary data, Appendix S2 available in *Age and Ageing* online), increasing by 12% in the winter compared with the rest of the year (IRR = 1.12, 95% CI: 1.04–1.21). Excluding hip fractures from injury events resulted in very similar IRRs to our primary definition for days with freezing rain alerts (Table 2), days with snowstorm alerts (Table 2) as well as for seasonal comparisons of fall-related injuries (Supplementary data, Table S2 available in *Age and Ageing* online). Finally, the rate of fall-related injuries generally dropped the day following a warning, but it increased and was (or remained) statistically significant, for up to 5 days after the event (Supplementary data, Appendix S2 available in *Age and Ageing* online). The highest rates were observed 4 and 5 days following an alert.

Table 1. The number of injury events, incidence rate and corresponding 95% confidence interval (CI) for the study population

	No. of events	Rate[a]	95% CI
All injuries			
Overall	23,829	8.56	(8.44–8.68)
Men	7,736	6.85	(6.70–7.02)
Women	16,093	9.72	(9.56–9.88)
Aged 65–74	9,548	6.12	(6.00–6.26)
Aged 75+	14,281	11.67	(11.47–11.87)
Hip fractures			
Overall	3,835	1.38	(1.33–1.42)
Men	892	0.79	(0.74–0.84)
Women	2,943	1.78	(1.71–1.84)
Aged 65–74	684	0.44	(0.41–0.47)
Aged 75+	3,151	2.57	(2.48–2.66)
All injuries, excluding hip fractures			
Overall	21,203	7.62	(7.51–7.73)
Men	7,116	6.31	(6.16–6.47)
Women	14,087	8.51	(8.36–8.66)
Aged 65–74	9,081	5.83	(5.70–5.96)
Aged 75+	12,122	9.91	(9.73–10.09)

[a]Per 100,000 person-days.

Discussion

We estimated the association between official weather warnings during the winter season and fall-related injury rates among older adults residing in the Montreal CMA from

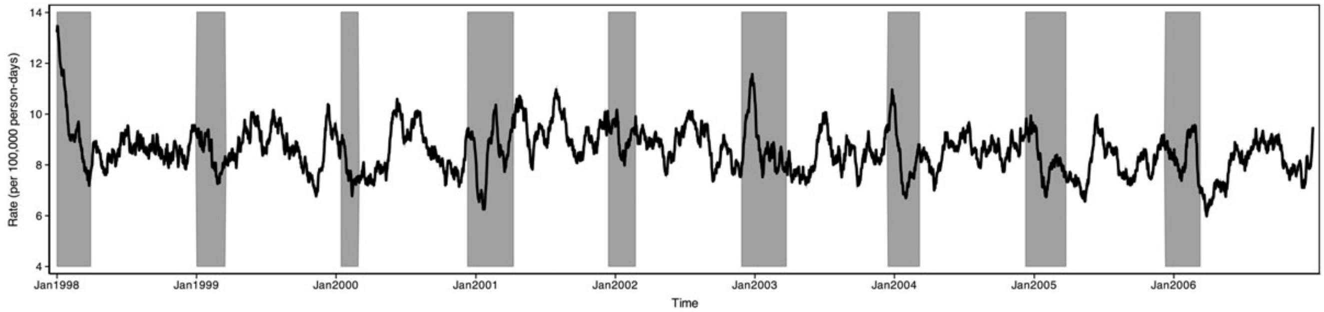

Figure 1. Time series (monthly moving average) of injury rates, per 100,000 person-days, for all individuals aged ≥65 over the study period. The defined winter season is shaded.

Table 2. The ratio of injuries in the winter: the day of freezing rain alerts and snowstorms alerts compared with days where no alert was issued (reference)

	Freezing rain alerts		Snowstorm alerts	
	IRR	95% CI	IRR	95% CI
All injuries				
Overall	1.20	(1.08–1.33)[a]	0.89	(0.80–0.99)[a]
Men	1.31	(1.10–1.56)[a]	0.91	(0.75–1.11)
Women	1.15	(1.01–1.30)[a]	0.88	(0.76–1.00)
Aged 65–74	1.24	(1.06–1.46)[a]	0.86	(0.72–1.03)
Aged 75+	1.17	(1.02–1.34)[a]	0.92	(0.79–1.05)
Hip fractures				
Overall	1.06	(0.80–1.37)	0.84	(0.63–1.11)
Men	1.05	(0.56–1.79)	0.66	(0.31–1.23)
Women	1.06	(0.77–1.42)	0.90	(0.65–1.21)
Aged 65–74	1.02	(0.49–1.87)	0.48	(0.17–1.06)
Aged 75+	1.07	(0.79–1.42)	0.94	(0.69–1.25)
All injuries, excluding hip fractures				
Overall	1.20	(1.08–1.34)[a]	0.89	(0.79–1.01)
Men	1.29	(1.07–1.55)[a]	0.93	(0.76–1.14)
Women	1.16	(1.01–1.32)[a]	0.87	(0.75–1.01)
Aged 65–74	1.28	(1.08–1.50)[a]	0.89	(0.74–1.06)
Aged 75+	1.15	(0.99–1.33)	0.91	(0.77–1.06)

[a]Statistically significant ($\alpha = 0.05$).

1998 to 2006. We found a 20% increase in fall-related injuries when hazardous freezing rain warnings were issued, with a notable increase for men, at 31%. This increased rate of fall-related injuries persisted for 4–5 days following a warning. In addition, we found an overall reduction in fall-related injuries on days with snowfall warnings.

Weather predictions have received considerable attention for public health planning and prevention of health outcomes [36]. For example, a surveillance system has been developed in the United Kingdom that monitors the impact of severe winter weather on emergency department use in near real time [37]. Elsewhere, in response to the excess morbidity and mortality experienced by vulnerable populations during heat waves, predictive weather forecasts are used to initiate public notifications and public health interventions [30]. In Canada, official hazardous freezing rain alerts are issued by Environment Canada when freezing rain is expected for ≥2 h or is expected to pose a hazard to transportation or property. These alerts are issued during, and in advance of, inclement weather. Our results suggest that these weather alerts could be used to trigger timely injury prevention and health promotion strategies to reduce the incidence of fall-related injuries among older adults. Strategies could include notifying vulnerable populations of the excess risk of injury and encouraging preventative behaviours, and also initiating timely snow and ice removal and walkway sanding by local public work departments, especially in areas where older adults tend to reside.

We explored the robustness of our findings through sensitivity analyses. In one analysis, we compared the rates of injuries on the days before and after freezing rain alerts with rates on all other days in the winter. As expected, nearly all IRRs were not statistically significant for any of the injury outcomes 1 or 2 days prior to the weather alert. Only one result was marginally statistically significant, but this result is likely to have occurred by chance given the number of comparisons examined. Following the warnings, we observed an immediate drop in the IRR, followed by an increase that lasted up to 5 days. This finding is consistent with previous research on hospitalisations following severe ice storms, which have been shown to peak up to 6 days following the event [38, 39]. This finding also suggests that our results are conservative estimates of the true impact of fall-related injuries when hazardous freezing rain warnings are issued, because these days were included in the reference set in our analyses.

In sensitivity analyses, we also internally validated our data, finding very similar counts for hip fracture events using claims data and hospitalisation data over the study period (see Supplementary data, Appendix 3 available in *Age and Ageing* online). Using physician claims data as opposed to hospitalisation data is advantageous for population surveillance as not all fall-related injuries result in inpatient admissions, especially for extremity fractures and soft-tissue injuries [40]. Other strengths of our study include considering a range of injury types using a previously validated code set, using a large, representative study sample, and using a long study period (9 years). In addition, we defined winter exposure based on having seasonal snow cover on the ground. Compared with a construct based on months of the year, our definition more accurately reflects the true winter exposure.

We also explored alternative definitions of fall-related injury events, including hip fractures, and their relationship to seasonality and winter weather warnings. We found that although hip fracture rates increased by 12% in winter compared with the rest of the year, no statistically significant differences in rates were observed on days with hazardous freezing rain or snowfall. This finding suggests that higher rates of fall-related hip fractures among older adults living in colder climates are likely associated with other mechanisms such as temperature or levels of physical activity. The opposite pattern was observed for all other types of injuries: no seasonal differences were observed, but increases in rates were associated with hazardous freezing rain alerts. Therefore, the results of our study support the hypothesis that freezing temperatures combined with untreated icy pavements increase the risk of slipping during the winter, leading to a range of injuries [**13**, **41**–**44**]. In support of this assertion, a marked increase in injuries was evident at the start of the study period which coincides with a severe ice storm that affected southern Quebec and nearby areas during that time [45].

Interestingly, snowstorms were not associated with an increase in fall-related injury rates and were even associated with a reduction of injury rates. This may be explained by low exposure to snowy weather among individuals in the population because during snowstorms, blizzards and periods of heavy snowfall, older adults are less likely to spend a significant amount of time outdoors [46, 47]. In addition, for those who venture outdoors during snowstorm and experience a fall, the impact may be cushioned due to the heavy snow cover on the ground. Our findings are also consistent with previous research on fall-related injuries that observed the highest incidence rates for both fall-related injuries and hip fractures in older age groups and in females [48].

There are limitations of our research worth noting. In contrast to other data sources, administrative records do not indicate whether a fall-related injury occurred outdoors or was directly attributable to hazardous weather. However, this limitation should result in random misclassification, which would likely attenuate any observed association. To identify fall-related injuries, we used diagnostic and procedure codes previously validated in the same setting with high sensitivity. With a positive predictive value of 79%, some misclassification of injuries as being fall-related is likely. Additionally, the specificity of this code set for injuries is unknown, although false positives in claims data are known to be low for other health conditions [49]. Finally, aggregating our data to the day allowed us to quantify associations with weather alerts, but small event counts, particularly for hip fractures, limited our statistical power and resulted in wide confidence intervals.

Conclusion

Among older adults living in the Montreal CMA, we found that severe weather alerts for freezing rain during the winter season were associated with increases in fall-related injuries and that the increased rate of injuries persisted for up to 5 days. The largest increase, 31%, was observed for males. Our study suggests that these weather alerts can therefore be used as a public health tool to initiate timely prevention strategies, including informing vulnerable populations of the incoming health risks and triggering response by public works departments.

Key points

- We found a statistically significant increase in fall-related injuries following freezing rain warnings, as issued by governmental meteorologists.
- This increase in injury rate persisted for up to 5 days following an alert and was most evident among men.
- Our findings suggest that weather alerts can be used by public health organisations to initiate timely injury prevention strategies targeting older adults in advance of inclement weather.

Conflicts of interest

None declared.

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Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

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The long list of references supporting this manuscript has meant that only the most important are listed here and are represented by bold type throughout the text. The full list of references is available in Supplementary data in *Age and Ageing* online.

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