ORIGINAL ARTICLE

Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada)

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ABSTRACT

Objective To quantify the associations between occupational injury compensations and exposure to summer outdoor temperatures in Quebec (Canada).
Methods The relationship between 374 078 injuries compensated by the Workers' Compensation Board (WCB) (between May and September, 2003–2010) and maximum daily outdoor temperatures was modelled using generalised linear models with negative binomial distributions. Pooled effect sizes for all 16 health regions of Quebec were estimated with random-effect models for meta-analyses for all compensations and by sex, age group, mechanism of injury, industrial sector and occupations (manual vs other) within each sector. Time lags and cumulative effect of temperatures were also explored.
Results The relationship between daily counts of compensations and maximum daily temperatures reached statistical significance for three health regions. The incidence rate ratio (IRR) of daily compensations per 1°C increase was 1.002 (95% CI 1.002 to 1.003) for all health regions combined. Statistically significant positive associations were observed for men, workers aged less than 45 years, various industrial sectors with both indoor and outdoor activities, and for slips/trips/falls, contact with object/equipment and exposure to harmful substances/environment. Manual occupations were not systematically at higher risk than non-manual and mixed ones.
Conclusions This study is the first to quantify the association between work-related injury compensations and exposure to summer temperatures according to physical demands of the occupation and this warrants further investigations. In the context of global warming, results can be used to estimate future impacts of summer outdoor temperatures on workers, as well as to plan preventive interventions.

What this paper adds?

- Little research has been conducted on the association between outdoor heat exposure and injuries in the workplace, and few industrial sectors have been identified as vulnerable.
- The mechanisms of injury involved and the potential impact of physical demands of the occupation on the relation between outdoor heat and work injuries remain unknown.
- Modelling daily work-related injury compensations and maximum daily outdoor temperatures revealed a 0.2% increase with each increase of 1°C. We observed statistically significant effects of temperature in industries with both outside and inside activities, particularly for accidents resulting from slips, trips and falls, contact with object/equipment and exposure to harmful substances/environment.
- The observed statistically significant increased risk according to physical demands of the occupations warrant further study as manual jobs were not systematically at higher risk than non-manual and mixed ones.
- The model developed in this study allowed for the identification of vulnerable groups and high-risk industries. In the context of climate change, results of this study could be helpful to estimate future impacts of global warming, as well as to plan preventive interventions.

INTRODUCTION

Direct effects of heat on occupational health have been recognised for some time. Several studies showed that both indoor and outdoor temperatures were associated with morbidity and mortality in the workplace.[1–9] For instance, a recent study in Canada reported an increase in the daily rate of emergency department visits for occupational heat illness with daily maximum temperatures.[10]

Heat exposure has also been shown to produce other effects on workers, such as physical discomfort, reduced vigilance and increased fatigue, which could lead to accidents and injuries.[11–16] The effect of heat on activities, performance and productivity is known to be complex. Working in hot environments may cause sweating, which may affect activities requiring grip and influence manual performance. In contrast, improvements of performance in the context of working in a hot environment have been reported.[17] As an example, Hancock and Vasmatzidis[18] propose that watch-keeping performance improvements are to be expected when an operator experiences a constant elevated internal body temperature (hyperthermic state) that does not exceed a normative comfort level.

Little research has been conducted on the association between outdoor heat exposure and these consequences. High outdoor temperature was associated with increase in injuries in the mining sector,[19] during army combat training[20] and in the textile manufacturing industry in India,[21] as well as with the increase in hospital admissions due to work-related accidents in Italy.[22] Very recently, the relationship between daily average summer temperatures and daily work-related injuries was quantified in South Australia[15] where it was observed that daily occupational injury compensations increased with temperature up to 37.7°C and declined above this threshold.

Thus, although the association between outdoor temperature and heat-related illnesses has been recently studied in Canada,[10 23] the association with work-related accidents has been little studied. The aims of this study were to quantify the associations between occupational injury compensations and exposure to summer outdoor temperatures in Quebec (Canada), and to identify vulnerable subgroups of workers and industrial sectors.

METHODS

The study was conducted in Quebec, Canada. The relationships between daily counts of compensations for work-related injuries and daily summer temperatures were quantified for all health regions of Quebec, from 1 May to 30 September 2003–2010.

Workers' compensation data

Workers' compensation data were obtained from the Workers' Compensation Board (WCB) of Quebec, which is the major provider of compensation for employment injuries in the province.[24] These data do not include injuries that occur while travelling from home to work and back.

Study population

In the WCB database, each accepted compensation claim includes information on the claimant (ie, identification number, date of birth and sex, Canadian Classification Dictionary of Occupations (CCDO) code assigned to the occupation), on the employer (ie, six digit postal code of the establishment's location, North American Industrial Classification System (NAICS) code assigned to the employer's record) and on the injury (ie, date, nature, mechanism of injury, exposure and sources, as classified by the Canadian Standards Association—Standard Z795). The WCB database does not provide computerised information on the detailed conditions of the occurrence of injuries, such as the location (indoor or outdoor) or the presence of air conditioning in the workplace.

For this study, compensations for accidental injuries that occurred between 1 May and 31 September—the warmest months in Quebec—were retained between 2003 and 2010 due to data availability. Only acute occupational injuries were retained for the analysis. When the same identification number appeared more than once in a 31-day period with the same information (claimant, employer and injury), only the first compensation was retained in the database to avoid double-counting of recurrent cases (less than 0.02% of compensations were excluded).

Daily counts of work-related injury compensations were calculated for the 16 health regions of Quebec, using the employer's establishment postal code to classify each claim within one of the regions (see figure 1 and see online supplementary table A2 for health region names). Stratification by sex, age categories as reported in the Labour Force Survey of Statistics Canada (15–24, 25–44 and 45 years old and more), mechanism of injury (see table 1 for categories) and by NAICS industrial sectors (see tables 2 and 3 for sector names) was applied to the regional daily counts of compensations.

To take into account physical demands of occupations, a rough indicator developed by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail was used to stratify regional daily compensation counts per industrial sector. The indicator groups the standard occupational codes into one of three categories of physical demands, that is, manual, non-manual and mixed demands, described as follows. Manual occupations require handling heavy or average loads on a regular basis, handling lighter loads in static postures or continuous repetitive work. Mixed occupations entail occasional handling of heavy or average loads or handling light loads, but not in continuous static postures. Finally, non-manual occupations rarely involve strenuous physical activities or handling of loads.[25]

Meteorological data

One monitoring station was selected per health region and meteorological data for each station was obtained from the Environment Canada Data Access Integration Team. These monitoring stations were previously identified by experts from Environment Canada as representative of the weather of each region.[26 27] For each station, the highest hourly value in the 8 h period between 9:00 and 17:00 was retained for dry bulb temperatures (°C) and relative humidity (%). Days with less than 75% of meteorological data (less than 2.5% of days in the study period) were excluded from statistical analysis.

Statistical analyses

The association between the daily counts of compensations for work-related injuries and daily hourly maximum dry bulb temperatures was assessed for the Montreal health region, and the characteristics of this model (ie, same adjustment) were then used to estimate the risks in the other health regions. Montreal, the largest urban area of the province, was chosen as this region had the highest compensation counts during the period of study. The risk function was developed using a generalised linear model with negative binomial regression. The model was adjusted for day, month, year, 2-week holiday in the construction sector and public holiday periods to control for temporal trends and for relative humidity, as high relative humidity may accelerate the increase of body temperature during heat exposure.[17 28] The likelihood ratio test was used to assess the effect of including the year, relative humidity and temperature as linear or cubic spline function variables with three knots located at 10, 50 and 90 percentiles of the temperature variable, according to Harrell.[29] The statistical interaction between temperature and relative humidity was verified by adding an interaction term. As an offset in the model, the monthly regional working population estimates obtained from the Labour Force Survey of Statistics Canada (table CANSIM 282-0001, http://www5.statcan.gc.ca/cansim/) were used. The autocorrelation was verified by producing correlograms (graphs of autocorrelations) for all data combined and also for every year of the study. There was no evidence of residual serial correlation in the tested models.

The developed model is as follows:

$$
\begin{aligned}
\ln[E(Yt)] &= \ln(\text{monthly working population estimates}) \\
&+ \beta_0 + \beta_{1-6}\text{day of the week} + \beta_{7-10}\text{month} \\
&+ \beta_{11-13}\text{year}_{(\text{cubic spline 3 knots})} \\
&+ \beta_{14}\text{construction sector holiday} + \beta_{15}\text{ public holiday} \\
&+ \beta_{16}\text{daily maximum relative humidity over 8 h} \\
&+ \beta_{17}\text{daily maximum temperature over 8h} + \varepsilon
\end{aligned}
$$

where E(Yt) is the expected daily count of work-related compensations.

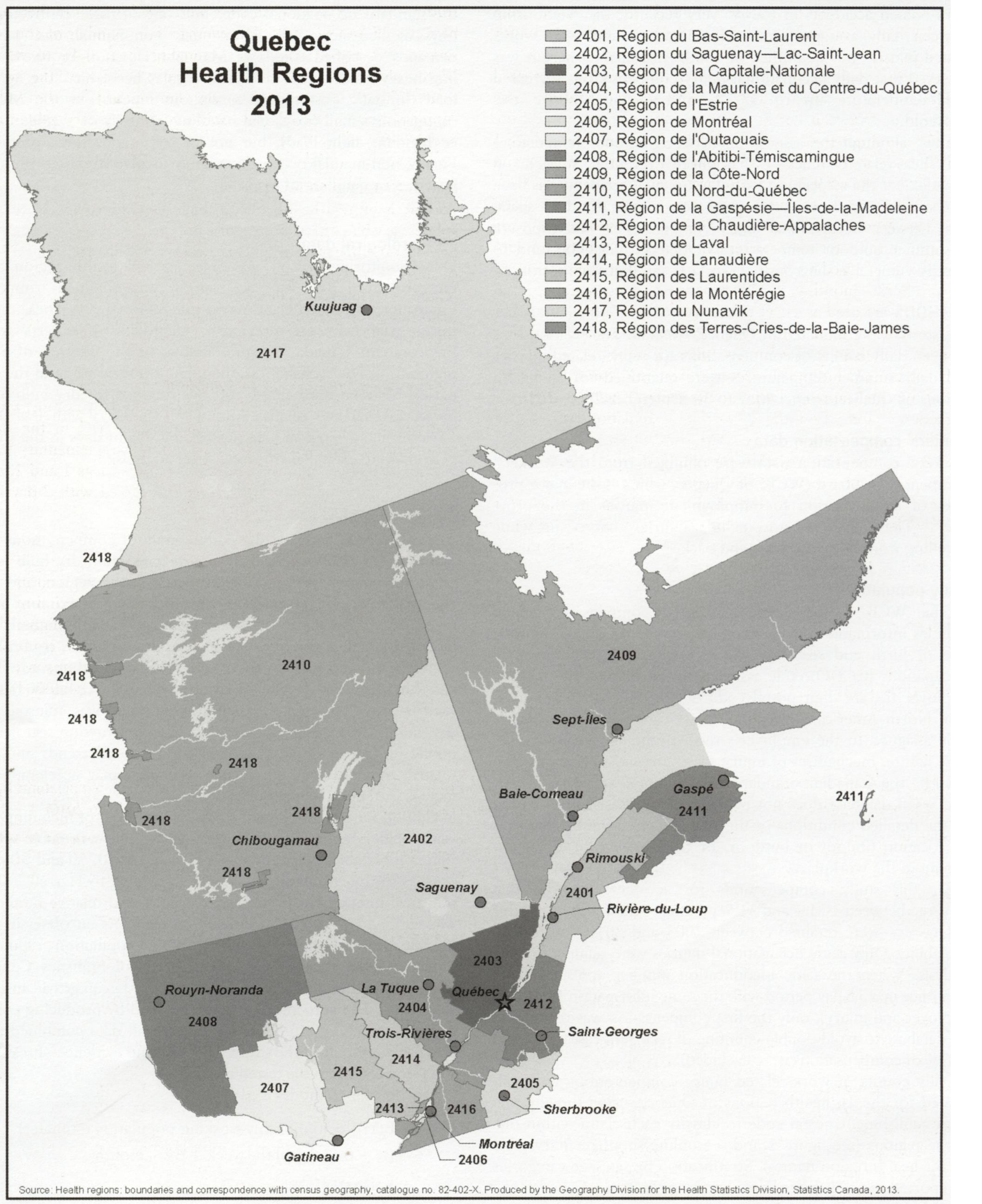

Figure 1 Localisation of the 16 health regions studied in Quebec (Canada). Nunavik (2417) and Terres-Cries-de-la-Baie-James (2418) were excluded from the analyses due to lack of meteorological or work-related data. A colour version of this figure is available with the online supplementary material.

As mentioned earlier, this model was used to estimate the risks in the other 15 health regions. In very few cases, the negative binomial model did not converge and Poisson regression was used instead, after checking the overdispersion with a deviance goodness-of-fit test. Incidence rate ratios (IRR) per 1°C increase and 95% CIs were obtained per health region; pooled effect sizes for all health regions combined were estimated using the DerSimonian and Laird random-effects model for meta-analysis.[30]

The same analyses were conducted to assess the potential delayed effect of temperature on work-related injuries. The associations between daily compensation counts and the weather conditions for each of the two previous days (lags 1 and 2) and of the cumulative 2-day (mean of lags 0–1) and 3-day (mean of lags 0-1-2) moving averages were assessed.

Additional analyses were performed on stratified data. Provincial pooled estimates by sex and age subgroups were obtained, and differences of temperature effects between subgroups were verified with Cochran Q test.[31] For these analyses, the provincial monthly working population estimate of each subgroup were used as offset term, because this information was not available at a regional level. Provincial pooled estimates were also obtained for each mechanism of injury, as well as for each group of industrial sectors. For the forestry/logging, fishing/hunting/trapping and mining/quarrying/oil and gas extraction sectors, the monthly working population estimate for the three groups combined was used as offset term, because this information was not available separately in the Labour Force Survey. Lastly, provincial pooled estimates were calculated for manual and other occupations (mixed and non-manual) for each industrial sector and Cochran Q test was used to compare the effect of outdoor temperatures between these subgroups of occupations. All analyses were performed with Stata V.12.1.

RESULTS

Overall, 374 078 work-related injury compensations were allocated during the 1224 days of the 8 years under study. Almost half of these occurred in the greater area of Montreal (working population of approximately 1.78 million during the period of study), on week days. Claimants were predominantly men aged between 25 and 44 years. The average daily number of compensations per region was 19.10, ranging from 0.46 to 85.48. Meteorological data and various characteristics of the work-related injury compensations are summarised in the online supplementary material (see online supplementary tables A-1 and A-2 and figure A-1).

Exposure–response relationship

For the Montreal health region, including the temperature as a spline variable (three knots) did not provide a better fit compared to the linear term (likelihood ratio test for the comparison of models: χ^2 test (df=1: 0.81; p value=0.39)). Therefore, the relationship between daily injury compensation counts and daily maximum temperatures was included as linear in the risk function.

Total and delayed effects of temperature

For all regions combined, a 0.2% increase in daily compensation counts was observed with each increase of 1°C in the daily maximum temperature (table 1; see online supplementary table A-2 for IRRs per region). IRRs were similar at lags 1 and 2, and stronger effects of temperatures were observed with 2-day and 3-day moving averages (table 1).

Sex and age stratification

A 0.3% increase in daily injury compensations counts was observed with each increase of 1°C in the daily maximum temperatures for men, whose risk ratio was significantly higher than that for women (heterogeneity χ^2 test, df=1: 14.35; p<0.001). A significant difference in the effect of temperatures between age subgroups was found (χ^2 test, df=1: 41.37; p<0.001) and the IRR was higher for younger workers (table 1).

Table 1 Daily work-related injury compensations counts, IRRs and 95% CIs associated with a 1°C increase in daily maximum temperatures by sex, age groups, mechanism of injury and for different time lags (all health regions of Quebec combined, May–September 2003 to 2010)*†

Classification	Number of compensations (%)	Mean daily count per region (range)	Pooled IRR per 1°C increase‡ (95% CI)
All accidents	374 078 (100)	19.10 (0;175)‡	1.002 (1.002 to 1.003)
Sex and age			
Women	110 844 (29.6)	5.66 (0;58)	1.000 (0.998 to 1.003)
Men	263 234 (70.4)	13.44 (0;130)	1.003 (1.002 to 1.005)
15–24 years old	59 668 (16.0)	3.05 (0;37)	1.008 (1.005 to 1.010)
25–44 years old	178 441 (47.7)	9.11 (0;100)	1.003 (1.001 to 1.004)
45 years old and more	135 969 (36.3)	6.94 (0;83)	1.000 (0.999 to 1.001)
Lag effects			
Lag 1	374 078 (100)	19.10 (0;175)	1.001 (1.000 to 1.002)
Lag 2	374 078 (100)	19.10 (0;175)	1.001 (1.000 to 1.002)
2-day average (lag 0-lag 1)	374 078 (100)	19.10 (0;175)	1.002 (1.001 to 1.003)
3-day average (lag0-lag1-lag2)	374 078 (100)	19.10 (0;175)	1.003 (1.001 to 1.004)
Mechanism of injury			
Transportation accidents	5 848 (1.6)§	4.8 (0;21)	1.003 (0.996 to 1.010)
Slips, trips and falls	57 709 (15.4)	47.1 (6;103)	1.003 (1.001 to 1.006)
Contact with object/equipment	114 472 (30.6)	93.5 (10;212)	1.004 (1.002 to 1.006)
Exposure to harmful substances/environment	18 748 (5.0)	15.3 (2;45)	1.009 (1.003 to 1.015)
Exertion/repetitive motion/bodily reaction	138 496 (37.0)	113.2 (17;274)	0.999 (0.997 to 1.001)
Other events/exposures and unknown	38 805 (10.4)	31.7 (2;76)	1.009 (1.003 to 1.015)

*Models were estimated with binomial negative or Poisson regression and were adjusted for day, month, year, public and construction sector holiday periods and relative humidity.
†Statistically significant heterogeneity was found between sex and age groups.
‡The provincial mean daily number of compensations was 306 ranging from 54 to 641.
§Including 3548 road accidents.
IRR, incidence rate ratio.

Mechanism of injury

Most compensated injuries occurred as a result of exertion/repetitive motion/bodily reaction, contact with object/equipment or slips, trips and falls. Statistically significant positive associations between daily maximum temperature and daily injury compensations were observed for slips, trips and falls, contact with object/equipment and exposure to harmful substances/environment, regardless of whether the workplace was mostly outside or not (table 1).

Industrial sectors and physical demands of the occupation

Statistically significant effects of temperature were found in sectors with mostly outside work, when taken altogether, but not consistently found in individual sectors (table 2). Although the effect of temperature was not statistically significant in sectors where activities are mostly inside, when taken together, some significant effects were also observed for a few individual sectors (table 3). When stratified according to physical demands of the occupation, statistically significant increased risks were observed but not similarly across industrial sectors, and manual occupations were not systematically at higher risk (tables 2 and 3). There were no differences in risk between overall outside and overall inside sectors for all occupations (df=1; 0.31 p=0.579), manual occupations (df=1; 1.23; p=0.268) and for other occupations (df=1; 0.17; p=0.676) according to heterogeneity χ^2 tests (data not shown).

DISCUSSION

In this study, a 0.2% increase in daily work-related injury compensations was observed with each increase of 1°C in daily maximum temperatures for all 16 regions combined. The increase was statistically significant in three of the regions, and was at or above 0.2% in eight other regions. The size of this effect of temperature is consistent with results from the few studies published on the subject, albeit with fairly different types of design or data. For instance, Fogleman *et al*[19] reported a significant relationship between categories of an outdoor heat index combining outdoor temperature (from −18 to 43°C) and relative humidity and acute injury in an aluminium smelter of the Midwest of the USA between 1997 and 1998. Authors observed significantly elevated ORs for categories of outdoor temperatures between 33°C and 38°C (OR=2.28; 95% CI 1.49 to 3.49) and over 38°C (OR=3.52; 95% CI 1.86 to 6.67) when compared to temperatures between 11°C to 16°C. In a study conducted in Florida between 1997 and 1998 on army basic combat training, Knapik *et al*[20] observed higher risks of injury in summer (temperatures from 30.8°C to 36.1°C) compared to fall (temperatures from 14.5°C to 26.1°C) for men (relative $\text{risk}_{\text{summer/fall}}$ of 2.0; 95% CI 1.7 to 2.3) and for women (relative $\text{risk}_{\text{summer/fall}}$ of 1.4; 95% CI 1.3 to 1.6). Hot weather conditions were also associated with increases in hospital admissions due to work-related accidents in Tuscany between the summer seasons of 1998 to 2003.[22] In this study, the peak of work accidents occurred on days characterised by a mean apparent temperature ranging from 24.8°C to 27.5°C.

Our findings are also similar to those of Xiang *et al*[15] who quantified the relationship between ambient temperatures and work-related injury compensations during the warm season in Adelaide (South Australia; 2001–2010). For all injuries combined, they calculated an IRR of 1.002 (95% CI 1.001 to 1.004) for every 1°C increase in maximum temperatures between 14.2°C and 37.7°C on the day of the injury, and a decrease by 1.4% per °C above this threshold. They reported no delayed effect of temperatures above the threshold of 37.7°C and did not explore delayed effects below it, whereas we observed similar effects of temperatures at lags 1 and 2 with a slightly stronger effect with 2-day and 3-day moving averages compared to lag 0.

Table 2 Daily work-related injury compensations counts, pooled IRRs and 95% CIs associated with a 1°C increase in daily maximum temperatures by industrial sector with mostly outdoor work* and stratified by type of occupation (manual and others) (all health regions of Quebec combined, May–September 2003 to 2010)†‡

	All occupations			Manual		Non manual and mixed occupations	
Classification	Number of compensations (%)	Mean daily count (range)	Pooled IRR per 1°C increase (95% CI)	Mean daily count (range)	Pooled IRR per 1°C increase (95% CI)	Mean daily count (range)	Pooled IRR per 1°C increase 95% CI
Sectors with mostly outside activities, overall							
	61 918 (16.6)	50.6 (1;124)	1.004 (1.001 to 1.006)	36.9 (0;100)	1.002 (1.000 to 1.005)	5.9 (0;19)	1.004 (0.991 to 1.018)
Agriculture							
	4 054 (1.1)	3.3 (0;12)	1.005 (0.993 to1.016)	2.72 (0;11)	1.002 (0.987 to 1.017)	0.13 (0;2)	1.041 (0.988 to 1.096)
Construction							
	29 784 (8.0)	24.3 (0;73)	1.003 (1.000 to 1.006)	19.36 (0;57)	1.003 (0.999 to 1.007)	1.19 (0;7)	0.992 (0.980 to 1.005)
Fishing, hunting and trapping							
	222 (0.06)	0.2 (0;3)	1.001 (0.927 to 1.082)	0.16 (0;3)	0.997 (0.929 to 1.069)	0.01 (0;2)	–
Forestry, logging and supporting activities							
	3 504 (0.9)	2.9 (0;15)	1.011 (1.001 to 1.020)	1.80 (0;13)	1.004 (0.989 to 1.019)	0.48 (0;4)	1.025 (1.004 to 1.048)
Mining, quarrying and oil and gas extraction							
	3 751 (1.0)	3.1 (0;12)	0.995 (0.984 to 1.006)	2.37 (0;10)	0.996 (0.988 to 1.005)	0.29 (0;3)	0.980 (0.955 to 1.006)
Transportation and warehousing							
	20 603 (5.5)	16.8 (0;46)	1.005 (1.001 to 1.009)	10.47 (0;29)	1.002 (0.995 to 1.009)	3.82 (0;14)	1.007 (1.003 to 1.011)

*Excluding 14 066 injury compensations (3.8%) with unspecified industrial sector.
†Models were estimated with binomial negative or Poisson regression and adjusted for day, month, year, public and construction sector holiday periods and relative humidity.
‡IRRs per NAICS sector (all occupations) and for manual and other occupations within each sector were mostly estimated with 16 health regions. Exceptions are presented in online supplementary material (see online supplementary table A-3).
IRR, incidence rate ratio.

Table 3 Daily work-related injury compensations counts, pooled IRRs and 95% CIs associated with a 1°C increase in daily maximum temperatures by industrial sector with mostly inside activities* and stratified by type of occupation (manual and others) (all health regions of Quebec combined, May–September 2003 to 2010)†‡

	All occupations			Manual		Non-manual and mixed occupations	
Classification	Number of compensations (%)	Mean daily count (range)	Pooled IRR per 1°C increase (95% CI)	Mean daily count (range)	Pooled IRR per 1°C increase (95% CI)	Mean daily count (range)	Pooled IRR per 1°C increase 95% CI
Sectors with mostly inside activities, overall	298 094	243.5 (51;502)	1.003 (1.000 to 1.005)	140.1 (16;328)	1.004 (1.001 to 1.006)	63.3 (19;114)	1.001 (0.997 to 1.005)
Accommodation and food services	17 543 (4.7)	14.3 (2;29)	1.007 (1.003 to 1.010)	4.85 (0;15)	1.005 (0.999 to 1.012)	7.36 (0;18)	1.006 (1.001 to 1.012)
Educational services	9 360 (2.5)	7.6 (0;37)	0.994 (0.989 to 0.999)	1.98 (0;12)	1.008 (0.998 to 1.018)	4.44 (0;21)	0.988 (0.981 to 0.994)
Finance and insurance	4 615 (1.2)	3.8 (0;13)	1.009 (0.999 to 1.019)	1.71 (0;8)	1.013 (0.999 to 1.027)	1.35 (0;7)	0.999 (0.987 to 1.011)
Health care and social assistance	48 576 (13.0)	39.7 (9;73)	0.999 (0.997 to 1.002)	17.98 (2;39)	1.001 (0.998 to 1.004)	16.90 (2;38)	0.997 (0.991 to 1.002)
Information/culture; arts/entertainment and recreation	6 988 (1.9)	5.7 (0;17)	1.004 (0.998 to 1.010)	2.29 (0;9)	1.002 (0.987 to 1.017)	2.25 (0;8)	1.007 (0.997 to 1.016)
Waste management/remediation services; administrative/support services	15 732 (4.2)	12.9 (0;43)	1.007 (1.003 to 1.011)	8.23 (0;26)	1.008 (1.003 to 1.013)	2.52 (0;21)	1.008 (0.997 to 1.019)
Manufacturing	107 940 (28.9)	88.2 (3;234)	1.002 (1.000 to 1.004)	67.84 (1;189)	1.001 (1.000 to 1.003)	5.22 (0;19)	1.005 (0.999 to 1.011)
Other services including repair and maintenance (not public administration)	11 959 (3.2)	9.8 (0;27)	1.005 (1.001 to 1.010)	7.20 (0;22)	1.010 (1.002 to 1.017)	1.77 (0;9)	0.990 (0.979 to 1.002)
Professional. scientific and technical services	2 652 (0.7)	2.2 (0;11)	1.002 (0.992 to 1.011)	0.53 (0;5)	1.002 (0.982 to 1.021)	1.10 (0;6)	0.999 (0.986 to 1.012)
Public administration	21 152 (5.7)	17.3 (1;43)	1.008 (1.004 to 1.011)	6.94 (0;26)	1.003 (0.996 to 1.010)	7.18 (0;22)	1.008 (1.003 to 1.014)
Utilities	1 418 (0.4)	1.2 (0;7)	0.987 (0.972 to 1.003)	0.70 (0;5)	0.979 (0.959 to 1.000)	0.21 (0;3)	0.998 (0.938 to 1.062)
Wholesale and retail trade	50 159 (13.4)	41.0 (1;99)	1.001 (0.999 to 1.004)	20.87 (0;62)	1.003 (1.000 to 1.006)	13.00 (1;33)	1.000 (0.997 to 1.004)

*Excluding 14 066 injury compensations (3.8%) with unspecified industrial sector.
†Models were estimated with binomial negative or Poisson regression and adjusted for day, month, year, public and construction sector holiday periods and relative humidity.
‡IRRs per NAICS sector (all occupations) and for manual and other occupations within each sector were mostly estimated with 16 health regions. Exceptions are presented in online supplementary material (see online supplementary table A-3).
IRR, incidence rate ratio; NAICS, North American Industrial Classification System.

In our study, the risk functions were modelled as log-linear because including the temperature as a spline variable did not provide a better fit compared to the linear term. Therefore, the shape of the relationship between temperature and work injuries is represented as log-linear, which contrasts with results from previous studies conducted in warmer countries, such as Australia[15] and Italy[22] where a non-linear relationship (ie, a reversed U-shaped relationship) between temperature and work injuries was observed. This difference in the shape of the relationships may be due to factors such as the implementation of effective protective measures like heat-related policies which advise or require the cessation of work when the temperature is extreme.[15] However, it is possible that a larger data set, a wider distribution of temperatures or a different time window in our study could have revealed a non-linear relationship.

We observed a statistically significant positive association for men only and no effect for women. For the same range of temperatures, Xiang *et al*[15] reported comparable findings. This possibly reflects gender differences in the industrial sector of employment in Quebec, where men constitute more than 70% of the workforce in agriculture, forestry, fishing, mining and oil and gas extraction and construction.[32] We also found higher IRRs for young workers (less than 25 years old), as observed in other studies[15 19] and this could be triggered by the more strenuous tasks and physical activity experienced by workers in this age group.[15]

Statistically significant effect of temperatures were observed in our study for accidents resulting from slips, trips and falls, contact with object/equipment and exposure to harmful substances/environment, regardless of whether the industrial sectors included mostly outside work or not. The only paper that reported on mechanisms of injury in association with outdoor heat compared injuries occurring during heatwave periods to those during non-heatwave periods, reporting that moving objects, contact with chemicals and injuries related to environmental factors were significantly associated with heatwaves.[33] In the USA, between 1985 and 1990, Hassi *et al*[34] observed increases in mining accidents caused by handling materials, machinery, powered haulage and hand tools with increases of ambient temperatures (ranging from 3°F to 89°F or approximately −16.1°C to 31.7°C).

In contrast with Xiang *et al*,[15] who found statistically significant effects only in industrial sectors with mostly outside work, we also found statistically significant IRRs for sectors where activities are mostly inside. This suggests that outdoor heat may add to the temperature burden resulting from heat-generating industrial processes, intense physical work and absence of heat-mitigating devices or policies on hot days. The effect of outdoor temperature also appears to vary with physical demands of the occupation, but not similarly across industrial sectors. For example, the only risk estimates that reached statistical significance in the industrial sectors with outdoor activities concerned the category that includes mixed and non-manual occupations. We could not find published data on the subject, but it is possible that these last types of occupations require more complex perceptual motor tasks which seem to be more influenced during heat exposure than simple motor tasks and which could potentially increase the risk of accidents.[1] The complex relation of heat on activities, performance and productivity, which could vary among participants and according to the task, has been highlighted,[17] and the intricate role of physical workload in detrimental effects of heat exposure warrants further study.

Methodological considerations

This study has limitations. First, it was impossible with the available data to discriminate injuries occurring indoors from those occurring outdoors and it is difficult to estimate the importance and direction of the effect resulting from the imperfect grouping. We thus reanalysed the data to obtain pooled estimates for industrial sectors with mostly outside (table 2) and with mostly inside (table 3) activities, as classified according to expert judgement. Overall, there were no differences between the effects of maximum temperature on injuries occurring in sectors with mostly outside and mostly inside activities for all, manual and for other occupations, although risk estimates were slightly higher for sectors with mostly outdoor work. Second, the effect of temperatures is likely to be underestimated as a large number of workers who mostly work outdoors are employed in sectors that are well known for under-reporting injuries, such as agriculture, forestry, fishing and construction.[35] Third, some exposure misclassification may have resulted from the selection of only one weather station per health region, even if these stations were previously identified as representative of the weather for each region.[26 27] Moreover, the fact that the employer's location (postal code) was used to link injuries and temperatures might have also introduced additional exposure misclassification for employees who are on the road or at remote worksites from their employer's location. In addition, we did not have information on the prevalence of air conditioning in sectors with mostly indoor work, which would have permitted to better discriminate the effect of outdoor temperature on injuries occurring indoors. Fourth, the use of less specific offsets may have influenced the results found for the sex and age analyses, and for some industrial sectors. However, we conducted sensitivity analyses with the regional monthly working population estimates (all workers per health region) and obtained similar results. In addition, some IRRs were not estimated in all the 16 health regions due to the small numbers of regional daily counts of compensations or because the fully-adjusted models did not converge with binomial negative or Poisson regressions. This dictates cautious interpretation of the results, especially for data stratified by type of occupation according to physical demands. Moreover, the adequacy of the risk function may be questioned because the model was developed with data from the largest urban region of Quebec and then applied for each of the other regions. Nevertheless, additional risk models were developed based on data from two rural health regions. The risk functions were the same (cubic spline function with three knots on the year variable, linear functions for temperature and relative humidity), with the only exception of an interaction term between temperature and humidity being significant in one of the two models.

A last limitation of the study concerns the use of temperature and humidity as indicators of heat stress, without considering the influence of other factors that could play an important role. The most widely used heat stress index in the occupational studies is the Wet Bulb Globe Temperature (WBGT) that takes into account air temperature, humidity, solar radiation and wind speed in a single index. The use of this index would have been preferable in our assessment as it would have given a more valid measure of the heat stress.[36] However, this index is not routinely measured and it is not available for every health region of Quebec, and we did not have the necessary data to estimate it.

CONCLUSION

This study is the first of its kind to quantify the impact of summer outdoor temperatures on work-related injuries in Canada. In the context of climate change, increases in global temperatures and in frequency and intensity of heat waves are expected, and the results of this study could be helpful to estimate future impacts of global warming on workers, as well as to plan preventive interventions.

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