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[1] The DAI portal is a collaborative effort of the Global Environmental and Climate Change Centre (GEC3), Environment Canada's Adaptation and Impacts Research Division (AIRD) and the Drought Research Initiative (DRI). The Ouranos (Quebec) consortium provided IT support to the DAI team.

ABSTRACT

Global warming is undeniable, and its impact on population health is a growing concern among scientists and public policy makers. Specialists are predicting not only that temperatures will rise in Quebec, but also that heat waves and heat emergencies will be longer and more intense. Other environmental parameters may also undergo changes with the increase in outdoor temperatures: for example, ambient concentrations of air pollutants, such as ground-level ozone, could rise.

These changes could have an impact on worker health and safety. The literature reports that exposure to outdoor heat can cause death, disease and possibly an increase in occupational injuries. However, the statistical relationship between outdoor temperature and the incidence of illness or accidents among workers is not well documented and has never been studied in conditions similar to those in Quebec. The same is true regarding the relationship between ozone and acute respiratory disorders in workers, while the effects of simultaneous exposure to heat and ozone have never been studied in this population.

The general objective of our study was to document these associations in a Quebec setting. To do so, we developed statistical models to (a) assess the association between outdoor summer temperature and occupational injuries accepted for compensation by the Commission de la santé et de la sécurité du travail (CSST, now named CNESST) [Quebec workers' compensation board] in connection with overexposure to heat (sunstroke, fainting, loss of consciousness, etc.) and work-related accidents; (b) explore the association between daily summer levels of tropospheric ozone and occupational injury claims for acute respiratory illnesses accepted for compensation. Last, we also wanted to identify subpopulations, industries and occupations most at risk for occupational injuries related to heat or tropospheric ozone concentrations.

Modelling suggests a log-linear relationship between outdoor summer temperatures in Quebec and daily counts of accepted injury claims for heat-related health problems and work-related accidents. Daily counts of accepted injury claims for heat-related health problems (mean daily number = 0.13, from 0 to 10) and work-related accidents (mean daily number = 306, from 54 to 641) increased an estimated 42% and 0.2%, respectively, for every 1°C increase in maximum daily temperature (range = −7.8°C to 37.3°C). Analyses also showed that the strength of the associations may vary depending on worker age, industrial sector and occupation's physical workload (manual labour or other). These results must be interpreted with caution, however, as the study has a number of limitations, including the use of compensation data (which contain little information about the exact circumstances of the occurrence of the injury or health problem) and imprecise workplace temperature and humidity values at the time of injury, which were estimated from regional data.

Given that summer temperatures in Quebec are expected to increase in coming years, it is essential to implement preventive measures specifically targeting those workers most likely to suffer from heat effects and to continue research to advance our knowledge in this field, in particular by using better heat stress indices. The low statistical power of the results regarding the association between acute respiratory illnesses and estimated ozone concentrations precludes

drawing any firm conclusions in this respect. As outdoor workers are nonetheless among those most exposed to ground-level ozone and other air pollutants, further study of this subject is clearly warranted.

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LIST OF ACRONYMS AND ABBREVIATIONS

95% CI 95% Confidence interval

CCDO Canadian Classification and Dictionary of Occupations

CSST Commission de la santé et de la sécurité du travail, now named Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST) [Quebec workers' compensation board]

FEV1 Forced expiratory volume in one second

FVC Forced vital capacity

IPCC Intergovernmental Panel on Climate Change

IRR Incidence rate ratio

ln Natural logarithm

NAICS North American Industry Classification System

OR Odds ratio

ppb Parts per billion

ppm Parts per million

WBGT Wet-bulb globe temperature

1. INTRODUCTION

Global warming is undeniable, and its impact on population health is a growing concern among scientists and public policy makers. Many global changes in weather and climate have been documented since 1950, including the increasing number of hot days and nights, and the Intergovernmental Panel on Climate Change (IPCC) is now predicting that the mean temperature at the Earth's surface will rise by 0.3°C to 4.8°C between 1986–2005 and 2081–2100 (IPCC, 2013).

In Quebec, summer temperatures are expected to rise 1.6°C to 3.0°C by 2050, and a 2010 study forecast that the length and intensity of heat waves and extreme heat would increase in the coming years (Desjarlais *et al.*, 2010). Changes of this kind can have an impact on worker health and safety. In a study on this topic, Adam-Poupart *et al.* (2012) identified rising summer temperatures and a higher number of days with extreme heat as a major issue for Quebec workers. This issue is related, among other things, to the effects of outdoor temperature on worker mortality and morbidity, as well as on an increased incidence of occupational injuries (see State of Knowledge section for a review of work published on this topic). Furthermore, other factors that might affect occupational health and safety in Quebec may also undergo changes as a result of higher outdoor temperatures. For instance, ambient concentrations of air pollutants such as ground-level ozone (tropospheric ozone), an irritant that can have acute and chronic effects on the respiratory system, could rise in summer (Desjarlais *et al.*, 2010; Health Canada, 2008). Workers will therefore be more exposed, and periods of simultaneous exposure to heat and tropospheric ozone could be more frequent, as it has been shown that ozone levels are higher on hot summer days (Ministère du Développement durable, de l'Environnement et des Parcs [MDDEP], 2002).

The main objective of this study was to document the associations between occupational injuries of Quebec workers, outdoor temperatures and tropospheric ozone.

2. STATE OF KNOWLEDGE

As mentioned, the potential health and safety effects of rising summer temperatures and increasing periods of extreme heat are a major issue for Quebec workers.

2.1 Direct Effects of Heat

The direct effects of heat on workers' health are well documented (for a review, see Jay and Kenny, 2010). Exposure to high ambient temperature triggers physiological mechanisms that can cause exhaustion and symptoms associated with heat stress, including cramps, syncope, fatigue, heatstroke and heat shock (LoVecchio *et al.*, 2007; National Oceanic and Atmospheric Administration, 2010; Intergovernmental Panel on Climate Change [IPCC], 2007). Furthermore, performing a physical activity for an extended period in a hot, humid environment increases the risks of exhaustion and heat shock (Tanaka, 2007; Kjellstrom *et al.*, 2009), in particular because high relative humidity in the air means less evaporation of sweat and therefore a reduced rate of heat dissipation.

Periods of extreme heat have been associated with increased fatalities among workers. During the heat waves of 2003 and 2006 in France, 15 and 8 deaths by hyperthermia, respectively, were reported among workers (Institut national de recherche et de sécurité [INRS], 2009; Buisson, 2009), while in the United States, 423 fatalities attributable to heatstroke occurred in the workplace between 1992 and 2006 (Centers for Disease Control [CDC], 2008). Even in Quebec, where the continental climate is slightly milder than in France or the United States, nine deaths associated with heatstroke were documented among workers between 1988 and 2003 (Tison, 2004). Generally speaking, industries where most of the work is performed outdoors, including construction, agriculture, forestry, fishing, hunting and utilities, have higher risks of fatalities on hot days (Buisson, 2009; CDC, 2008; Fortune *et al.*, 2013; INRS, 2009).

Only two studies have estimated the relationships between mean summer temperature and number of fatalities from hyperthermia in the workplace, and have produced contradictory results. A U.S. study on the risk of death from heart disease among firefighters at work revealed that the risk was not associated with an increase in temperature during months when the mean temperature was above 5°C, between 1994 and 2004 (Mbanu *et al.*, 2007). Another study, conducted between 1977 and 2001 on heat-related fatalities among workers in North Carolina, reported a 37% increase in the risk of death for each 1°F increase in the mean summer temperature (which corresponds to approximately 77% per 1°C) (Mirabelli and Richardson, 2005).

Outdoor heat is also responsible for an increase in the incidence of certain health problems (e.g., heatstroke) during the hottest months of the year, as was seen among Ontario workers between 2004 and 2010 (Fortune *et al.*, 2013), among Washington state workers between 1995 and 2005 (Bonauto *et al.*, 2007) and, more specifically, among forestry and mining industry workers (Donoghue *et al.*, 2000; Donoghue, 2004; Maeda *et al.*, 2006). A recent review of the literature has also reported that the workers most commonly affected by heat-related health problems were those in agriculture, construction, mining and manufacturing, as well as firefighters and military personnel (Xiang *et al.*, 2014a). The relationship between daily summer temperatures and worker morbidity has only been estimated once, in a five-year pilot study done by the Florida Department of Health (2012). In that study, the authors reported daily increases in the number of hospital admissions or emergency room visits for heat-related illnesses of the order of 62% to 258% for each 5°F increase in maximum daily temperature (which corresponds approximately to daily increases of 20% to 60% per 1°C) depending on the location in Florida.

According to a recent review of the literature on the association between ambient temperature and morbidity (for several nonspecific diagnoses) in the general population, most studies describe the harmful effects of temperature lasting up to three days following exposure, which points to a delayed, cumulative effect of heat (Ye *et al.*, 2012). According to the Florida Department of Health study, the increase in the number of hospital admissions among workers was discernable the same day or, as a delayed effect, the day after hot days (Florida Department of Health, 2012).

2.2 Indirect Effects of Heat

Exposure to outdoor heat can also affect worker safety. Physical discomfort, deteriorating psychomotor performance, fatigue and reduced alertness are all signs and symptoms of heat exposure well documented in occupational health (Ramsey, 1995; Tawatsupa *et al.*, 2010; Grandjean and Grandjean, 2007). All these phenomena may be responsible for work-related accidents.

Only a few studies have examined the association between outside temperature exposure and occupational accidents. In India, a study of textile industry workers found that accident prevalence was significantly higher in summer, when outdoor temperatures reached between 42°C and 48°C (Nag and Nag, 2001). In Italy, Morabito and colleagues (2006) reported that hot weather was associated with an increase in hospital admissions for workplace accidents during the summers from 1998 to 2003. In that study, the highest number of hospital admissions for occupational accidents during the summer was found on days when the mean apparent temperature reached between 24.8°C and 27.5°C, i.e., on hot days, whereas the number was lower before and after temperatures reached these levels. The authors pointed out that this effect was more noticeable in June than in the other summer months, a finding they attributed to workers gradually becoming acclimatized to the heat. In these two studies, no measure of association between daily outdoor temperature and occupational injuries was estimated.

However, in a study conducted in an aluminum smelter in the U.S. Midwest in 1997–98, Fogleman and colleagues (2005) reported significantly higher acute injury risks when the heat index, combining outdoor temperature and relative humidity, was between 32°C and 38°C (odds ratio [OR] 2.28; 95% Confidence Interval [95% CI] 1.49–3.49) or over 38°C (OR 3.52; 95% CI 1.86–6.67), compared with periods where the heat index ranged between 10°C and 16°C.

Another study, which focused on U.S. military personnel training in Florida between 1997 and 1998, showed that among physically active individuals, injuries are more frequent in summer than in fall (Knapik *et al.*, 2002). The study's authors reported very strong linear relationships between daily maximum temperature (between 16.2°C and 34.2°C) and the incidence of injuries of all kinds, with correlations varying between 0.92 and 0.97. Last, a very recent Australian study estimated the association between maximum daily temperature in summer and daily number of compensated work-related injuries (Xiang *et al.*, 2014b). A daily increase in injuries of 0.2% was found for each 1°C increase in maximum daily temperature between 14.2°C and 37.7°C, and the number declined by 1.4% per degree of temperature above 37.7°C (a decline likely attributable, say the authors, to preventive activities done when temperatures are very high). Agriculture and construction, like other industries where most work is done outdoors, were identified as particularly likely to see injuries on hot days.

2.3 Effects of Simultaneous Exposure to Heat and Tropospheric Ozone

It has been noted that periods of simultaneous exposure to both heat and tropospheric ozone could be more frequent in future, as ozone levels are higher on hot summer days (MDDEP, 2002). The combined effect of heat and ozone on respiratory illnesses has never been assessed among workers, and very little research has documented the impact of exposure to this pollutant. To the best of our knowledge, only six studies have reported on it.

A decline in respiratory function (ratio of forced expiratory volume in one second to forced vital capacity [FEV1/FVC]) was observed for each 10 $\mu g/m^3$ increase in mean daily ozone level among beach lifeguards in the United States between 2002 and 2004 (Thaller *et al.*, 2008). Ozone, say the authors, can cause pulmonary obstruction or bronchoconstriction. The authors of two studies of the same group of berry pickers in Canada's Fraser Valley conducted in the summer of 1993 reported associations between an increase in maximum daily ozone concentrations over an hour and a decline in respiratory functions (FEV1 and FVC) that could last through to the next day (Brauer *et al.*, 1996; Brauer and Brook, 1997). In a 2001 study done in China, declines in respiratory flow rates associated with an increase in tropospheric ozone concentrations over eight hours were observed among mail carriers up to three days after exposure (Chan and Wu, 2005). In Greece, another study of mail carriers also found that between February 2004 and April 2005, the probability of reporting rhinitis rose 7% (OR 1.07; 95% CI 1.02–1.12) for every 1 $\mu g/m^3$ increase in tropospheric ozone (Karakatsani *et al.*, 2009). Last, in a study conducted in 100 buildings in the United States between 1994 and 1998, Apte and colleagues (2008) highlighted the fact that a 10 $\mu g/m^3$ rise in daily ozone concentration matched a 3% increase (OR 1.03; 95% CI 1.00–1.06) in the probability of reporting symptoms of upper respiratory illnesses, e.g., sinus and nasal passage congestion, sore throat or sneezing, among clerical workers.

Conversely, a study of several populations (senior citizens, juvenile asthmatics, athletes, forestry workers and office clerks) conducted in Germany during the summers from 1992 to 1994 found that increases in respiratory tract resistance were similar among clerical workers and forestry workers on days with high ozone levels (mean maximum concentration over 30 minutes greater than 0.05 ppm between 1 p.m. and 4 p.m.), in relation to days with low levels (mean maximum concentration over 30 minutes greater than 0.04 ppm but less than 0.05 ppm between 1 p.m. and 4 p.m.) (Hoppe *et al.*, 1995).

2.4 Conclusion

As noted, outdoor heat can have effects on worker health and safety, and very few estimations have been made of the relationship between exposure to outdoor summer daily temperature and the occurrence of illnesses or accidents among workers. In addition, knowledge about the respiratory effects of short-term (e.g., daily) exposure to tropospheric ozone among workers is incomplete, and the effects of simultaneous exposure to temperature and tropospheric ozone have never been documented.

3. RESEARCH OBJECTIVES

The general objective of this study was to explore the associations between occupational injuries accepted for compensation by the Commission de la santé et de la sécurité du travail (CSST, now named CNESST) [Quebec workers' compensation board], outdoor temperature and tropospheric ozone.

More specifically, the study sought to:

1) Estimate the association between daily summer outdoor temperature and daily number of occupational injury claims accepted for health problems related to overexposure to heat (sunstroke, syncope, loss of consciousness, etc.)
2) Estimate the association between daily summer outdoor temperature and daily number of occupational injury claims accepted for workplace accidents
3) Explore the association between daily summer levels of tropospheric ozone and occupational injury claims accepted for acute respiratory illnesses
4) Explore the effect of simultaneous exposure to temperature and daily tropospheric ozone levels on the daily number of occupational injury claims accepted for acute respiratory illnesses
5) Identify the subpopulations, industries and occupations most at risk of occupational injuries in connection with temperature and daily tropospheric ozone levels.

4. METHOD

The study examines CSST-accepted occupational injuries suffered by workers in 16 health regions in Quebec (see Table 2 for the names of the regions) between May 1 and September 30 of each year from 1998 to 2010, inclusive. The study months cover the period when hot weather can occur in Quebec, while the study years were chosen on the basis of data availability.

4.1 Occupational Injury Data

The data used come from CSST administrative files for all reported occupational injuries among workers covered by the province's workers' compensation plan for which compensation benefits were paid out. In the files, injuries are coded by nature (principal physical characteristics of the injury or disease), event or exposure (that led to the injury), part of the body affected and source of injury (causal agent), based on a classification from the Canadian Standards Association standard CSA Z-795, which has been adapted by the CSST. The CSST classification differs from standard CSA Z-795 with respect to only a few codes.

For this analysis, only occupational injuries classified as work-related accidents by the CSST and accepted for compensation were selected. Injuries classified as occupational diseases and resulting from long-term exposure were excluded in order to limit individual exposure classification errors. For occupational diseases, the date associated with the injury corresponds to the date of diagnosis and not to the date when the injury occurred. Under the definition used by the CSST,[2] a work-related accident may cause an injury, but may also lead to a disease or discomfort, e.g., heatstroke.

So as not to count the same injury twice, because of recurrences, when the same identification number appeared more than once during each 31-day period for the same injury (identical nature, event or exposure, and source), the first claim was selected. As a result, 191 injuries out of 735,312 were excluded.

4.2 Study Population

The characteristics (nature and event or exposure) of the occupational injuries selected for health problems related to overexposure to heat (objective 1), for work-related accidents (objective 2) and for acute respiratory illnesses (objectives 3 and 4) are presented in Table 1. For exploratory purposes, less-specific health problems for which the injury source or event or exposure could be linked to environmental heat exposure were also selected, and their characteristics are also included in the same table.

[2] According to the CSST, an occupational disease is "a disease contracted out of or in the course of work and characteristic of that work or directly related to the risks peculiar to that work" and an industrial accident (workplace accident) is "a sudden and unforeseen event, attributable to any cause, which happens to a person, arising out of or in the course of his work and resulting in an employment injury to him" (Québec, 2013).

The information in the accepted-injury files included an identification number, the worker's date of birth and sex, the date the injury occurred, the employer's postal code, the injury characteristics (nature, part of the body, event or exposure, source), the North America Industry Classification System (NAICS) code corresponding to the industry of the employer's workers' compensation premium rate file and the Canadian Classification and Dictionary of Occupations (CCDO) code corresponding to the worker's occupation. In cases where the postal code of the employer's establishment was missing (49,157/735,312 claims) or when it was erroneous (1,814/735,312 claims), the postal code of the regional CSST office located in the administrative region where the worker resided was used.

All the selected files were associated with one of the 16 health regions in Quebec by the employer's postal code or the regional CSST office's postal code. Age groups were defined according to the categories most commonly used in occupational health and safety: age 15–24, 25–44, 45 and over.

Table 1 – Criteria used to include or exclude occupational injuries accepted for compensation, classified as accidents by the CSST, and selected for analysis

Type of injury	Inclusion and exclusion criteria
Heat-related health problems (objective 1)	**Nature** 07200 Effects of heat and light, unspecified 07210 Heat stroke 07220 Heat syncope 07280 Multiple effects of heat and light 07290 Effects of heat and light, n.e.c., including heat fatigue and heat edema **EXCEPT** **Event or exposure:** 32300 Contact with hot objects or substances
Work-related accidents (objective 2)	**Nature** Division 0 Traumatic injuries and disorders Division 0 Systemic diseases and disorders Division 0 Infectious and parasitic diseases Division 0 Neoplasms, tumours and cancer Division 0 Symptoms, signs and ill-defined conditions Division 0 Others diseases, conditions and disorders Division 0 Multiple diseases, conditions and disorders Division 0 Cannot be classified
Acute respiratory illnesses (objectives 3 and 4)	**Nature** Major group 14 Respiratory system diseases **EXCEPT** **Event or exposure** 34320 Bee, wasp, hornet sting 34400 Ingestion of substance
Less-specific health problems for which the injury source or accident type could be linked to environmental heat exposure (supplementary exploratory analyses)	**Nature** 07000 Effects of environmental conditions, unspecified 07900 Effects of environmental conditions, n.e.c. 41130 Malaise and fatigue 41150 Non-specific allergic reaction 41140 Dizziness 48000 Multiple symptoms, signs and ill-defined conditions, unspecified 48100 Multiple chemical sensitivity 49000 Other symptoms, signs and ill-defined conditions, n.e.c. 59000 Other diseases, conditions and disorders, n.e.c. 80000 Multiple diseases, conditions and disorders 99990 Cannot be classified **AND** **1. Primary source of injury:** Temperature extremes – environmental, unspecified (93600); Heat – environmental (93620); Weather and atmospheric conditions, n.e.c. (93790); Sun (93920) **OR** **2. Secondary source of injury**: Heat – environmental (93620); Sun (93920) **OR** **3. Event or exposure:** Exposure to environmental heat (32100); Exposure to radiation, unspecified (36000); Exposure to sun (36100); Exposure to radiation, n.e.c. (36900) **AND** **Primary source of injury**: Cannot be classified, unknown (99990); or not identified

n.e.c.: not elsewhere classified

4.3 Weather Data

The hourly weather data come from Environment Canada's Data Access Integration portal.

The analysis of accepted injuries associated with exposure to heat required classifying weather data according to the 16 health regions defined by the Quebec government. For each health region, a weather station already identified by Environment Canada as representative of the region's conditions (Martel *et al.*, 2010) was chosen. One of the heat stress indices most commonly used in occupational health is the wet-bulb globe temperature (WBGT) (Parsons, 2003; Health Canada, 2011). This index, which takes into account humidity, wind speed, air temperature and solar radiation, is unfortunately not measured by Environment Canada and is not available across Quebec. The highest hourly temperature between 9 a.m. and 5 p.m. was selected for the dry and wet thermometer temperatures (°C) (hereafter called dry and wet temperatures), as well as for relative humidity (%). Wet thermometer temperatures differ from dry thermometer temperatures by a value that varies with the water vapour content in the air (Environment Canada, 2013). Daily exposure was assumed to be constant for all workers within the same region. Days with less than 75% of the expected weather data were excluded (less than 2.5% of the study periods).

4.4 Tropospheric Ozone Concentrations

Ozone concentrations vary significantly on a small scale, both spatially and temporally (Beckerman *et al.*, 2008) and for that reason, we chose to use estimates of daily mean concentrations for all the postal codes of employer establishments associated with accepted injuries for acute respiratory illnesses, rather than estimates by health region, which would offer less precision. These concentrations come from a spatiotemporal forecasting model, based on probability densities estimated according to the maximum entropy principle, which was developed for Quebec by members of our research group (Adam-Poupart *et al.*, 2013, 2014). This model estimates mean daily ozone concentrations for each one kilometre square cell across the study area[3] using SEKS-GUI v. 0.69.5, a free geostatistical software package (http://140.112.63.249/SEKSGUI/SEKSHome.html). A summary of the development of the model can be found in Appendix 1.

For the analyses, the employer's postal code was positioned in a grid of the study area made up of one kilometre square cells, and the mean daily concentration of tropospheric ozone for the period from 9 a.m. to 5 p.m. was then estimated.

4.5 Statistical Analysis

Two approaches were used to analyse the data: ecological and case-crossover designs. The relationships between temperature and accepted occupational injuries were established with an

[3] The study area encompassed all dissemination areas where the population density was greater than five people per square kilometre in 2006 according to Statistics Canada data (2007) and that were located approximately between 42 and 50 degrees north latitude and between 60 and 80 degrees east longitude.

ecological approach (daily time series), in which health data (in this case, injury claims accepted for compensation) were daily counts of accepted injuries by health region, and the heat exposure data were assigned on the basis of temperature measurements obtained from one monitoring station representative of the health region. We chose this approach because of the accessibility of the data and the fact that the weather stations had already been identified by Environment Canada (Martel *et al.*, 2010). Generalized linear models with negative binomial regression were used, and incidence rate ratios and their 95% confidence intervals (95% CI) were estimated for each 1°C increase in maximum daily temperature.

The relationships between ozone and accepted occupational injuries were established using a case-crossover design in order to take into consideration ozone concentration estimates that provided better representation of geographic and temporal variations in this pollutant. In this type of approach, temporal trends are adjusted for by comparing exposure to temperature during the "case" days (days when one or more injuries occurred) with that on reference days (same days of the week of the same month, but with no injuries). For this approach, conditional logistic regressions were used, in which mean daily concentrations of tropospheric ozone for the period from 9 a.m. to 5 p.m. estimated on case days were compared with those estimated on reference days, and odds ratios and their 95% confidence intervals for a one part per billion (ppb) increase in ozone were estimated.

4.5.1 Association Between Accepted Injuries and Exposure to Heat

First of all, daily numbers (hereafter called daily counts) of injury claims accepted for heat-related health problems, for less-specific health events and for work-related accidents were calculated by health region and stratified by sex, age group and industry (two-digit NAICS breakdown). The possibility of a delayed effect of heat exposure (hereafter called time lag) was explored by considering the temperature the day before and two days before the injury occurred. The daily counts by industry were also broken down by an occupation's physical workload indicator developed by the IRSST (Hébert *et al.*, 1996).[4] This indicator, called "occupational category of physical workload", divides workers up into manual, mixed and non-manual categories. Work-related accidents were also stratified by event or exposure of accident.

Health risks were then described using two risk functions, which were first estimated for the region with the greatest number of accepted occupational injuries, Montreal, and then used for all regions. The first risk function concerned injury claims accepted for heat-related health problems, while the second had to do with all injury claims accepted as work-related injuries. No risk function was modelled for less-specific health events. (See section 5.1.2.2 for further details.)

[4] Under the IRSST's classification system, a manual worker "performs a job requiring the handling of medium to heavy loads on a regular basis," a mixed worker "performs a job requiring the handling of light loads and a discontinuous static posture or the occasional handling of medium to heavy loads" and a non-manual worker "performs a job where the loads handled and physical activity are negligible" (Hébert et al., 1996).

The risk functions were developed using negative binomial regression and adjusted for temporal trends. Daily relative humidity maxima measured between 9 a.m. and 5 p.m. were included in both models, as a rough indicator of humidity.

For both models, the variables “year,” “relative humidity” and “temperature” were included as linear or cubic spline function variables with three knots, according to the results of the likelihood ratio test. A two-way interaction term between maximum daily temperature, between 9 a.m. and 5 p.m., and maximum daily relative humidity for the same eight-hour period (continuous variables) was included when the models were developed, but was not used in the analyses because it was not statistically significant. The estimates of the number of workers at risk, i.e., the adjustment factor, or offset variable, for the two risk functions were the monthly number of workers by region, as obtained in Statistics Canada’s Labour Force Survey (CANSIM 282-0001 –). Note that the estimates of the number of workers at risk in the Mauricie and Centre-du-Québec regions were aggregated, as the corresponding health region (RSS 03) takes in these two regions.

The risk function model developed for Montreal for heat-related health problems is as follows:

ln [E(Yt)] = ln (Monthly estimate of number of workers at risk) + β_0 + $\beta_{1–6}$ Day of the week + $\beta_{7–10}$ Month + β_{11} Year + β_{12} Construction industry vacation + β_{13} Public holidays + β_{14} Daily maximum relative humidity over 8 hours + β_{15} Daily maximum temperature over 8 hours + ε

where E(Yt) is the expected value, i.e., the estimated daily count of injury claims accepted for health problems related to overexposure to heat, β_0 is the regression coefficient of the model when all the other variables are nil, $\beta_{1–15}$ are the regression coefficients associated with each variable of the model and ε is a random variable indicating the degree of precision of the estimate. The day of the week, the construction industry vacation and public holidays were incorporated into the model because these variables are strongly associated with the occurrence of accidents (Brogmus, 2007).

The model developed for Montreal for work-related accidents is essentially the same as the one above except that the year was modelled using a natural cubic spline function with three knots.

The two models were then applied to Quebec’s other health regions. In rare situations, the use of the negative binomial regression did not converge. Poisson regression was then used when the data were not overdispersed. The overall effect, for Quebec as a whole (pooled effect size for all regions), was estimated using a DerSimonian and Laird random-effects model for meta-analysis (Borenstein *et al.*, 2010).

The same procedures were performed on the data stratified by sex and age group. Cochran’s Q tests were then used to check the statistical significance of the differences of the effects of temperature between strata, i.e., between men and women, and between 15–24-year-olds, 25–44-year-olds and those aged 45 or older (Kaufman and MacLehose, 2013).[5]

For work-related accidents, the same analyses were done on the data stratified by event or exposure of accident, industry[6] and occupational category of physical workload (manual versus mixed and non-manual). Cochran's Q tests were used to check the statistical significance of the differences of the effects of temperature between worker subgroups for each industry. These stratified analyses were not carried out for heat-related health problems owing to the low number of accepted injuries by industry in the health regions (see Table 2 for further details).

The delayed effect of temperature was explored by modelling daily counts of injury claims accepted for health problems or for work-related accidents in relation to daily maximum dry temperatures measured on the two days preceding the day of injury (time lag 1 and time lag 2). These effects were compared using a Z-test. The cumulative effect of temperature was also assessed by calculating the incidence rates with the mean daily maximum temperatures over two (time lag 0–1) and three days (time lag 0–2). Last, the use of wet temperatures was also assessed in the models.

4.5.2 Association Between Accepted Injuries and Exposure to Tropospheric Ozone

The association between daily injury claims accepted for acute respiratory illnesses and mean daily concentrations of tropospheric ozone was estimated using a case-crossover epidemiological design (Maclure, 1991). In these analyses, reference days were chosen using a stratified temporal approach in which the study period was divided into months, and the reference days for each injury were the same day of the week as the case day, but in the other weeks of the month. Thus, if an acute respiratory illness occurred on Tuesday, May 12, 2009, the injury's reference days corresponded to all the other Tuesdays of the month, that is, May 5, 19 and 26, 2009.

ORs and their 95% CI for a one part-per-billion increase in ozone were thus calculated using conditional logistical regressions for all accepted injuries, then for injuries that occurred in industries where a large part of the work is done outdoors: *Agriculture; Construction; Forestry and logging; Fishing, hunting and trapping; Mining, quarrying, and oil and gas extraction;* and *Transportation and warehousing.*

The delayed effect of tropospheric ozone was also explored by estimating the ORs (and their 95% CI) for the association between accepted injuries and the estimated ozone concentration the day before (time lag 1) and two days before (time lag 2) the injury occurred.

[5] For these analyses, the adjustments associated with the number workers at risk were monthly estimates of each of these strata for the province as a whole because regional information was not available.

[6] For the *Forestry and logging*; *Fishing, hunting and trapping*; and *Mining, quarrying, and oil and gas extraction* industries, the offset variable (adjustment factor) for the population of workers at risk was the monthly regional numbers of workers for all these sectors.

Last, all the analyses were also adjusted for mean daily temperature. The data were obtained from the Data Access Integration portal hosted by Environment Canada, and the statistical significance of the interaction term between temperature and tropospheric ozone was verified for each analysis.

All the analyses were performed using Stata software, release 12.1.

5. RESULTS

In this section, the weather data and tropospheric ozone concentrations used to estimate worker exposure are presented. The analyses of accepted injuries are then explained. Last, estimates of statistical associations between dry temperature and injuries, as well as between tropospheric ozone concentrations and accepted injury claims for acute respiratory illnesses, whether temperature is considered or not, are reported.

5.1 Descriptive Data

5.1.1 Weather Data and Tropospheric Ozone Concentrations

Over the entire study period, the maximum daily dry temperature per region varied between −7.8°C and 37.3°C and the daily mean for the province as a whole was 20.2°C. The months of May and September were the coldest months of the study period, while the highest temperatures were recorded in July and August. The maximum daily ranges of relative humidity and wet temperature were, respectively, 22% to 100% and −8.8°C to 29.4°C, depending on the region. The mean daily ozone concentrations varied between 25.3 and 33.1 ppb. The maximum daily temperatures and estimated mean daily concentrations of tropospheric ozone by region are presented in Appendix 2 (Table A-1).

5.1.2 Accepted Occupational Injury Claims

In the following subsections, the characteristics of the injuries selected for analysis are presented. The numbers, daily counts and frequency rates of accepted injuries for heat-related health problems, work-related accidents and acute respiratory illnesses are presented in Table 2, while information on time distributions, sociodemographic characteristics of the individuals who received compensation for their injuries and injury characteristics (nature and event or exposure) is provided in Appendix 3 (tables A-2, A-3 and A-4). Less-specific health events are discussed briefly in section 5.1.2.2.

5.1.2.1 Heat-Related Health Problems

A total of 259 heat-related injuries, including six fatalities, were accepted for compensation by the CSST, between May and September, from 1998 to 2010. Those injuries occurred in 15 health regions, with around 44% of them in the Greater Montreal area (Montreal, Laval, Montérégie). The daily count of accepted injuries varied between 0 and 6 per region, and the provincial mean was 0.13 injuries per day for all regions combined. The mean frequency rate for the province was 0.04 injuries per million workers per day.

Over the study period as a whole, no heat-related injuries occurred when the maximum daily temperature was below 10°C; close to a third of the injuries occurred when the temperature was above 30°C (3% of the study period's 31,824 region-days).

Most injuries occurred on weekdays in July and August. The vast majority of workers whose injury claims were accepted for compensation were men, aged between 25 and 44, and the industries most often concerned were *Manufacturing* (29.8%), *Public administration* (20.8%) and *Construction* (10.7%). Around 23% of the injuries occurred in industries where most work is done outdoors, such as *Construction* (10.7%), *Forestry and logging* (4.5%), *Transportation and warehousing* (3.4%), *Agriculture* (2.2%) and *Mining, quarrying and oil and gas extraction* (1.7%) (Table A-2 in Appendix 3). The occupations that accounted for the highest proportion of accepted injuries were all labouring and materials-handling jobs (33%), including those in metal processing (5%), along with firefighters (11%) and truck drivers (4%).

5.1.2.2 Less-Specific Problems

Only 32 injuries related to less-specific health problems were accepted for compensation by the CSST between May and September, from 1998 to 2010. Among the 32, cases of dizziness (25%) and injuries that could not be classified (44%) were the most common. Most of those injured were men over age 25. One industry sector was associated with 17 injuries, and 6 of those occurred in *Manufacturing*. As only a small number of injuries concerned less-specific health problems, no further analysis was done.

5.1.2.3 Work-Related Accidents

Since the vast majority of the analyses conducted on work-related accidents concerned daily counts stratified by industry (NAICS economic sector) and since the CSST did not begin using that classification for administrative purposes until 2003, only the injury claims accepted for compensation between 2003 and 2010 were analysed, so as to allow better comparison of risk estimates.

Thus, for the years from 2003 to 2010, between May and September, 374,078 work-related accidents were accepted for compensation by the CSST in Quebec's 16 health regions. The most commonly accepted accidents resulted from the following event or exposure: overexertion/repetitive motion and other bodily reactions (37.0%), contact with objects and equipment (30.6%) and falls/slips, trips and loss of balance without fall (15.4%) (Table A-4 b, in Appendix 3).

Close to half of the accidents occurred in the Greater Montreal area (Montreal, Laval, Montérégie) and most involved men aged 25 to 44 and happened on weekdays. The mean daily number of accepted injuries for the province was 306 (between 54 and 641 per day) and the daily frequency rate for all regions combined was 8.0 per 100,000 workers (between 1.4 and 17.5).

Work-related accidents were accepted for compensation chiefly in the following sectors: *Manufacturing* (28.9%), *Wholesale and retail trade* (13.4%), *Health care and social assistance* (13.0%), *Construction* (8.0%), *Public administration* (5.7%) and *Transportation and warehousing* (5.5%). Materials-handling workers, delivery drivers and nurse's aides are the occupations associated with the greatest number of occupational injuries for work-related accidents.

5.1.2.4 Acute Respiratory Illnesses

A total of 598 injuries associated with acute respiratory illnesses were accepted for compensation by the CSST in Quebec between May and September, from 1998 to 2010. In 458 of these cases, a mean concentration of tropospheric ozone was estimated for analytic purposes for the case days and the reference days (with three or four reference days per case day) (Table A-2, Appendix 3).

Over 60% of the injuries occurred in Montreal and Montérégie, and most workers whose injury claims were accepted for compensation were men aged 25 or older. The most common accepted injuries had to do with substance inhalation (20.1%) or exposure to caustic, noxious, or allergenic substances (n.e.c. and unspecified) (32.3%).

Industry information is available for the vast majority of injuries (242/252 between 2003 and 2010) and 10.4% of them were in sectors where most work is performed outdoors and where workers have potentially greater exposure to tropospheric ozone. For comparison purposes, the workforce of these sectors accounts for approximately 11.4% of all Quebec workers.

Table 2 – Number, daily count and frequency rates of occupational injuries associated with heat-related health problems, work-related accidents and acute respiratory illnesses (16 health regions of Quebec)[1]

	Heat-related health problems (1998–2010)			Work-related accidents (2003–2010)			Acute respiratory illnesses[2] (1998–2010)		
	Number (relative frequency in %)	Mean daily counts (range)	Mean daily rate per 1,000,000 workers (range)	Number (relative frequency in %)	Mean daily counts (range)	Mean daily rate per 100,000 workers (range)	Number (relative frequency in %)	Mean daily counts (range)	Mean daily rate per 1,000,000 workers (range)
Bas-Saint-Laurent	8 (3.1)	0.004 (0; 2)	0.04 (0.00; 20.88)	10,332 (2.8)	8.44 (0; 25)	8.8 (0.0; 26.6)	13 (2.8)	0.01 (0.00; 1.00)	0.07 (0.00; 12.22)
Saguenay–Lac-Saint-Jean	21 (8.1)	0.011 (0; 1)	0.09 (0.00; 8.44)	14,112 (3.8)	11.53 (0; 37)	9.2 (0.0; 28.4)	3 (0.7)	0.00 (0.00; 1.00)	0.01 (0.00; 8.29)
Capitale-Nationale	14 (5.4)	0.007 (0; 2)	0.02 (0.00; 5.31)	36,902 (9.9)	30.15 (3; 69)	8.5 (0.8; 20.4)	25 (5.5)	0.01 (0.00; 2.00)	0.04 (0.00; 5.47)
Mauricie et Centre-du-Québec	22 (8.5)	0.011 (0; 2)	0.05 (0.00; 8.88)	23,070 (6.2)	18.85 (0; 53)	8.2 (0.0; 24.0)	29 (6.3)	0.01 (0.00; 3.00)	0.07 (0.00; 13.69)
Estrie	11 (4.2)	0.006 (0; 1)	0.04 (0.00; 7.39)	14,952 (4.0)	12.22 (0; 37)	8.2 (0.0; 24.7)	23 (5.0)	0.01 (0.00; 1.00)	0.08 (0.00; 7.37)
Montreal	60 (23.3)	0.030 (0; 4)	0.03 (0.00; 4.32)	104,633 (28.0)	85.48 (14; 175)	9.2 (1.5; 19.4)	170 (37.1)	0.09 (0.00; 5.00)	0.10 (0.00; 6.22)
Outaouais	5 (1.9)	0.003 (0; 1)	0.01 (0.00; 6.67)	9,189 (2.5)	7.51 (0; 24)	4.1 (0.0; 13.6)	13 (2.8)	0.01 (0.00; 1.00)	0.04 (0.00; 6.26)
Abitibi-Témiscamingue	4 (1.5)	0.002 (0; 1)	0.03 (0.00; 15.72)	7,570 (2.0)	6.18 (0; 19)	9.3 (0.0; 29.8)	4 (0.9)	0.00 (0.00; 1.00)	0.03 (0.00; 15.82)
Côte-Nord	7 (2.7)	0.004 (0; 1)	0.06 (0.00; 18.73)	5,647 (1.5)	4.61 (0; 14)	8.7 (0.0; 26.8)	–	–	–
Nord-du-Québec	0 (0)	0	0	562 (0.2)	0.46 (0; 5)	0.9 (0.0; 8.9)	–	–	–
Gaspésie–Îles-de-la-Madeleine	5 (1.9)	0.003 (0; 1)	0.07 (0.00; 28.41)	4,118 (1.1)	3.36 (0; 13)	9.0 (0.0; 34.9)	–	–	–
Chaudière-Appalaches	18 (6.9)	0.009 (0; 2)	0.04 (0.00; 9.02)	25,131 (6.7)	20.53 (0; 55)	9.7 (0.0; 26.1)	11 (2.4)	0.01 (0.00; 2.00)	0.03 (0.00; 11.15)
Laval	15 (5.8)	0.008 (0; 2)	0.04 (0.00; 10.69)	17,914 (4.8)	14.64 (0; 40)	7.6 (0.0; 21.1)	17 (3.7)	0.01 (0.00; 1.00)	0.05 (0.00; 6.39)
Lanaudière	21 (8.1)	0.011 (0; 6)	0.05 (0.00; 33.20)	16,923 (4.5)	13.83 (0; 37)	6.2 (0.0; 16.6)	14 (3.1)	0.01 (0.00; 1.00)	0.03 (0.00; 5.71)

	Heat-related health problems (1998–2010)			Work-related accidents (2003–2010)			Acute respiratory illnesses[2] (1998–2010)		
	Number (relative frequency in %)	**Mean daily counts (range)**	**Mean daily rate per 1,000,000 workers (range)**	**Number (relative frequency in %)**	**Mean daily counts (range)**	**Mean daily rate per 100,000 workers (range)**	**Number (relative frequency in %)**	**Mean daily counts (range)**	**Mean daily rate per 1,000,000 workers (range)**
Laurentides	9 (3.5)	0.005 (0; 1)	0.02 (0.00; 4.58)	21,989 (5.9)	17.96 (0; 46)	6.8 (0.0; 19.1)	25 (5.5)	0.01 (0.00; 3.00)	0.05 (0.00; 12.97)
Montérégie	39 (15.1)	0.020 (0; 2)	0.03 (0.00; 2.91)	61,034 (16.3)	49.86 (3; 113)	7.1 (0.4; 16.9)	111 (24.2)	0.06 (0.00; 3.00)	0.08 (0.00; 4.41)
16 regions combined	259 (100)	0.130 (0; 10)	0.04 (0.00; 2.49)	374,078	306 (54; 641)	8.0 (1.4; 17.5)	458	0.23 (0.00; 6.00)	0.06 (0.00; 1.84)

[1] No analysis was done of the Nunavik region because of the low number of injuries and the lack of data on the variables used in modelling (weather data and estimated total number of workers in the region).

[2] Acute respiratory illnesses for which a tropospheric ozone concentration was estimated.

5.2 Relationship Between Temperature and Accepted Occupational Injuries

5.2.1 Heat-Related Health Problems

The variable "temperature" was modelled log-linearly for each health region (likelihood ratio test for comparison between simple linear models and models with (three knots) natural spline function: χ^2[df = 1] = 0.91; p = 0.339) and this relationship was statistically significant for 14 of the 15 health regions where there were accepted injuries, the lone exception being the Bas-Saint-Laurent region; the IRRs by region are presented in Table A-5 in Appendix 4. An increase of approximately 42% (combined estimate for all regions; 95% CI: 33%–52%) in injuries accepted for compensation, for each 1°C increase in maximum daily temperature, was estimated by the model. The effect of the temperature of the two preceding days, as well as of the mean temperatures of two and three days, was also statistically significant (Table 3).

The IRR per 1°C increase was higher among men than among women, and higher among younger workers (15–24 and 25–44) than older ones. These differences were not statistically significant, however.

The modelling of the association between wet temperature and health problems in connection with overexposure to heat revealed an effect greater than that obtained with dry temperature in a model adjusted for relative humidity (combined IRR 1.486; 95% CI 1.411–1.567).

Table 3 – Number of injuries, mean daily counts of accepted injuries for heat-related health problems and incidence rate ratio associated with a 1°C increase in maximum temperature, by sex, age group and time lags (all Quebec health regions combined, May to September, 1998–2010)

Classification	Number of accepted injuries (%)	Mean daily counts by region (range)	IRR[1] (95% CI)
All accepted injuries (16 regions)	259 (100)	0.130 (0; 10)	1.419 (1.326–1.520)
Sex[2,3] (6 regions)			
Women	45 (17.4)	0.02 (0; 4)	1.430 (1.210–1.690)
Men	214 (82.6)	0.11 (0; 7)	1.409 (1.250–1.589)
Age[3,4] (6 regions)			
15–24	35 (13.5)	0.02 (0; 4)	1.436 (1.163–1.772)
25–44	149 (57.5)	0.07 (0; 6)	1.462 (1.284–1.665)
45 or older	75 (29.0)	0.04 (0; 3)	1.395 (1.162–1.677)
Delayed effect (16 regions)			
Time lag 1	259 (100)	0.130 (0; 10)	1.322 (1.255–1.392)
Time lag 2	259 (100)	0.130 (0; 10)	1.206 (1.161–1.252)
Two-day mean (time lag 0–time lag 1)	259 (100)	0.130 (0; 10)	1.471 (1.373–1.576)
Three-day mean (time lag 0–time lag 1–time lag 2)	259 (100)	0.130 (0; 10)	1.464 (1.376–1.557)

95% CI: confidence interval of 95%; IRR: incidence rate ratio

1 IRR estimated by negative binomial or Poisson regression, with adjustment for day of the week, month, year, construction industry vacation, public holidays and relative humidity.

2 IRR estimated with data from six regions (Saguenay, Estrie, Montreal, Chaudière-Appalaches, Laval, Montérégie) where there were injury claims approved for compensation for health problems in connection with overexposure to heat in each subgroup and convergence of the statistical models after adjustment.

3 No statistically significant heterogeneity observed between IRRs of compared groups.

4 IRR estimated with data from six regions (Saguenay, Estrie, Montreal, Lanaudière, Laurentides, Montérégie) where there were injury claims approved for compensation for health problems in connection with overexposure to heat in each subgroup and convergence of the statistical models after adjustment.

5.2.2 Work-Related Accidents

As earlier, the variable “temperature” was modelled log-linearly for all health regions (likelihood ratio test for comparison between simple linear models and models with (three knots) natural spline function: $\chi^2[df = 1] = 0.81$; $p = 0.3688$) and a statistically significant effect of the maximum daily temperature was observed on the daily work-related accident counts for 3 health regions out of 16, i.e., Mauricie et Centre-du-Québec, Montreal and Laval (the IRRs by region are presented in Table A-5, Appendix 4). For all regions combined, a statistically significant increase of 0.2% (95% CI: 0.2%–0.3%) in accepted injuries per 1°C increase in temperature was seen. Similar IRRs were obtained for the temperature effect of the two days preceding the injury accepted for compensation (time lags 1 and 2) and the extent of the effect was greater when calculated using mean temperatures from the preceding days (Table 4).

For men, an increase of 0.3% in daily accident claim counts was seen for each 1°C increase in temperature. This percentage increase was greater, in statistically significant terms, than that for women (Cochran's test: $\chi^2[df = 1] = 14.35$; $p < 0.0001$). In addition, statistically significant differences in the effects of temperature were observed among the various age groups (Cochran's test: $\chi^2[df = 1] = 41.37$; $p < 0.0001$), with the youngest (ages 15–24) having the highest IRR (Table 4).

Table 4 – Number of injuries, mean daily counts of accepted injuries for work-related accidents and incidence rate ratio associated with a 1°C increase in maximum temperature, by sex, age group and time lags
(all Quebec health regions combined, May to September, 2003–2010)

Classification	Number of accepted injuries (%)	Mean daily counts (range)	IRR[1] (95% CI)
All accepted injuries (16 regions)	374,078 (100)	19.10 (0; 175)[3]	1.002 (1.002–1.003)
Sex[2] (6 regions)			
Women	110,844 (29.6)	5.66 (0; 58)	1.000 (0.998–1.003)
Men	263,234 (70.4)	13.44 (0; 130.0)	1.003 (1.002–1.005)
Age[2] (6 regions)			
15–24	59,668 (16.0)	3.05 (0; 37)	1.008 (1.005–1.010)
25–44	178,441 (47.7)	9.11 (0; 100)	1.003 (1.001–1.004)
45 or older	135,969 (36.3)	6.94 (0; 83)	1.000 (0.999–1.001)
Delayed effect (16 regions)			
Time lag 1	374,078 (100)	19.10 (0; 175)	1.001 (1.000–1.002)
Time lag 2	374,078 (100)	19.10 (0; 175)	1.001 (1.000–1.002)
Two-day mean (time lag 0–time lag 1)	374,078 (100)	19.10 (0; 175)	1.002 (1.001–1.003)
Three-day mean (time lag 0–time lag 1–time lag 2)	374,078 (100)	19.10 (0; 175)	1.003 (1.001–1.004)

95% CI: confidence interval of 95%; IRR: incidence rate ratio

1 IRR estimated by negative binomial or Poisson regression, with adjustment for day of the week, month, year, construction industry vacation, public holidays and relative humidity.

2 Statistically significant heterogeneity of IRRs between women and men and among age groups.

3 Mean daily counts of 306 (range: 54–641) for the province.

Variations in daily work-related accident counts (Table 2) and their associations with temperature were observed between industries. A statistically significant positive association between temperature and number of accidents was seen for industries where most work is done outdoors, including *Transportation and warehousing*, and *Forestry and logging*, as well as for other types of industries, including *Business services, building-related services and other support services; Accommodation and food services; Public administration;* and *Other services except public administration* (Table 5). Once the data had been stratified by occupational category, statistically significant increases in daily accidents associated with an increase in temperature were observed for manual occupational categories in *Business services, building-related services and other support services; Administrative and support*, *waste management and remediation services;* and in *Other services except public administration*, and for mixed and non-manual occupational categories in *Transportation and warehousing*, *Forestry and logging*, *Accommodation and food services*, and *Public administration* (Table 5).

Table 5 – Mean daily work-related accident counts and incidence rate ratio associated with a 1°C increase in maximum temperature, by industry and occupational category of physical workload (manual, mixed and non-manual)
(all Quebec health regions combined, May to September, 2003–2010)

Industrial sector (NAICS code)	Mean daily counts (range)	IRR[1,2] (95% CI)	Occupational category of physical workload	Mean daily counts (range)	IRR[1,3,4] (95% CI)
Sectors where most work done outdoors					
Agriculture (111–112, 1151–1152)	3.3 (0; 12)	1.005 (0.993–1.016)	Manual	2.72 (0; 11)	1.002 (0.987–1.017)
			Mixed/non-manual	0.13 (0; 2)	1.041 (0.988–1.096)
Construction (23)	24.3 (0; 73)	1.003 (1.000–1.006)	Manual	19.36 (0; 57)	1.003 (0.999–1.007)
			Mixed/non-manual	1.19 (0; 7)	0.992 (0.980–1.005)
Fishing, hunting and trapping (114)	0.2 (0; 3)	1.001 (0.927–1.082)	Manual	0.16 (0; 3)	0.997 (0.929–1.069)
			Mixed/non-manual	0.01 (0; 2)	-
Forestry and logging (113, 1153)	2.9 (0; 15)	1.011 (1.001–1.020)	Manual	1.80 (0; 13)	1.004 (0.989–1.019)
			Mixed/non-manual	0.48 (0; 4)	1.025 (1.004–1.048)
Mining, quarrying, and oil and gas extraction (21)	3.1 (0; 12)	0.995 (0.984–1.006)	Manual	2.37 (0; 10)	0.996 (0.988–1.005)
			Mixed/non-manual	0.29 (0; 3)	0.980 (0.955–1.006)
Transportation and warehousing (48–49)	16.8 (0; 46)	1.005 (1.001–1.009)	Manual	10.47 (0; 29)	1.002 (0.995–1.009)
			Mixed/non-manual	3.82 (0; 14)	1.007 (1.003–1.011)
Other sectors					
Accommodation and food services (72)	14.3 (2; 29)	1.007 (1.003–1.010)	Manual	4.85 (0; 15)	1.005 (0.999–1.012)
			Mixed/non-manual	7.36 (0; 18)	1.006 (1.001–1.012)
Educational services (61)	7.6 (0; 37)	0.994 (0.989–0.999)	Manual	1.98 (0; 12)	1.008 (0.998–1.018)
			Mixed/non-manual	4.44 (0; 21)	0.988 (0.981–0.994)
Finance, insurance, real estate, leasing (52–53)	3.8 (0; 13)	1.009 (0.999–1.019)	Manual	1.71 (0; 8)	1.013 (0.999–1.027)
			Mixed/non-manual	1.35 (0; 7)	0.999 (0.987–1.011)
Health care and social assistance (62)	39.7 (9; 73)	0.999 (0.997–1.002)	Manual	17.98 (2; 39)	1.001 (0.998–1.004)
			Mixed/non-manual	16.90 (2; 38)	0.997 (0.991–1.002)

Industrial sector (NAICS code)	**Mean daily counts (range)**	**IRR[1,2] (95% CI)**	**Occupational category of physical workload**	**Mean daily counts (range)**	**IRR[1,3,4] (95% CI)**
Information and cultural industries; Arts, entertainment and recreation (51, 71)	5.7 (0; 17)	1.004 (0.998–1.010)	Manual	2.29 (0; 9)	1.002 (0.987–1.017)
			Mixed/non-manual	2.25 (0; 8)	1.007 (0.997–1.016)
Business services, building-related services and other support services; Administrative and support, waste management and remediation services (55–56)	12.9 (0; 43)	1.007 (1.003–1.011)	Manual	8.23 (0; 26)	1.008 (1.003–1.013)
			Mixed/non-manual	2.52 (0; 21)	1.008 (0.997–1.019)
Manufacturing (31–33)	88.2 (3; 234)	1.002 (1.000–1.004)	Manual	67.84 (1; 189)	1.001 (1.000–1.003)
			Mixed/non-manual	5.22 (0; 19)	1.005 (0.999–1.011)
Other services – except public administration (81)	9.8 (0; 27)	1.005 (1.001–1.010)	Manual	7.20 (0; 22)	1.010 (1.002–1.017)
			Mixed/non-manual	1.77 (0; 9)	0.990 (0.979–1.002)
Professional, scientific and technical services (54)	2.2 (0; 11)	1.002 (0.992–1.011)	Manual	0.53 (0; 5)	1.002 (0.982–1.021)
			Mixed/non-manual	1.10 (0; 6)	0.999 (0.986–1.012)
Public administration (91)	17.3 (1; 43)	1.008 (1.004–1.011)	Manual	6.94 (0; 26)	1.003 (0.996–1.010)
			Mixed/non-manual	7.18 (0; 22)	1.008 (1.003–1.014)
Utilities (22)	1.2 (0; 7)	0.987 (0.972–1.003)	Manual	0.70 (0; 5)	0.979 (0.959–1.000)
			Mixed/non-manual	0.21 (0; 3)	0.998 (0.938–1.062)
Wholesale and retail trade (41, 44–45)	41.0 (1; 99)	1.001 (0.999–1.004)	Manual	20.87 (0; 62)	1.003 (1.000–1.006)
			Mixed/non-manual	13.00 (1; 33)	1.000 (0.997–1.004)

95% CI: confidence interval of 95%; IRR: incidence rate ratio; NAICS: North American Industry Classification System

1 IRR estimated by negative binomial or Poisson regression, with adjustment for day of the week, month, year, construction industry vacation, public holidays and relative humidity.

2 IRR by industrial sector estimated on basis of 16 health regions, except for the following sectors: *Agriculture* (*n* = 13), *Forestry and logging* (*n* = 13), *Fishing, hunting and trapping* (*n* = 3), *Mining, quarrying, and oil and gas extraction* (*n* = 13), *Utilities* (*n* = 14), *Information and cultural industries; Arts, entertainment and recreation* (*n* = 15), *Professional, scientific and technical services* (*n* = 15), *Business services, building-related services and other support services; Administrative and support, waste management and remediation services* (*n* = 15).

3 IRR for manual occupational categories estimated for 16 health regions, except for the following sectors: *Agriculture* (*n* = 13), *Forestry and logging* (*n* = 13), *Fishing, hunting and trapping* (*n* = 3), *Mining, quarrying, and oil and gas extraction* (*n* = 12), *Utilities* (*n* = 12), *Transportation and warehousing* (*n* = 14), *Information and cultural industries*; *Arts, entertainment and recreation* (*n* = 14), *Finance, insurance, real estate, leasing* (*n* = 14), *Professional, scientific and technical services* (*n* = 13), *Business services, building-related services and other support services; Administrative and support, waste management and remediation services* (*n* = 15), *Health care and social assistance* (*n* = 15).

4 IRR for other occupational categories of physical workload (mixed and non-manual), estimated on basis of 16 health regions, except for the following sectors: *Agriculture* (*n* = 8), *Forestry and logging* (*n* = 11), *Mining, quarrying, and oil and gas extraction* (*n* = 9), *Utilities* (*n* = 8), *Transportation and warehousing* (*n* = 13), *Information and cultural industries; Arts, entertainment and recreation* (*n* = 14), *Finance, insurance, real estate, leasing* (*n* = 14), *Professional, scientific and technical services* (*n* = 14), *Business services, building-related services and other support services; Administrative and support, waste management and remediation services* (*n* = 14), *Health care and social assistance* (*n* = 15).

Statistically significant positive associations between daily temperature and daily work-related accident counts were observed for falls/slips and trips without fall, contact with objects and equipment, exposure to harmful substances or environments, and for other events/exposures of unknown type (see Table A-6, Appendix 5).

The effect of temperature on work-related accidents was similar when estimated with dry temperature in a model adjusted for relative humidity, or with wet temperature (IRR all regions combined 1.002; 95% CI: 1.001–1.003; data not presented).

5.3 Relationship Between Tropospheric Ozone and Acute Respiratory Illnesses

The odds ratios obtained for the association between estimated tropospheric ozone concentrations and occupational injury claims accepted for acute respiratory illnesses were all positive, albeit nonsignificant, for sectors where most work is done outdoors (Table 6). Furthermore, for these sectors, adjusting the models for temperature weakens the association between estimated ozone concentrations and acute respiratory illnesses, and the interaction between mean daily temperature and tropospheric ozone is nonsignificant for all odds ratios ($p > 0.24$) (Table 6).

Table 6 – Number of days with occupational injury claims accepted for acute respiratory illnesses and odds ratios for each 1 ppb increase in tropospheric ozone concentrations, with and without adjustment for temperature[1]

Type of mean estimated	Number of days with injury claims accepted	All injuries (1998–2010)		Number of days with injury claims accepted	All injuries (2003–2010)		Number of days with injury claims accepted	Sectors where most work done outdoors[3] (2003–2010)	
		OR (95% CI)[3]			OR (95% CI)[3]			OR (95% CI)[3]	
		Not adjusted	Adjusted[4]		Not adjusted	Adjusted[4]		Not adjusted	Adjusted[4]
Daily mean, time lag 0	458	1.00 (0.99; 1.02)	1.00 (0.98; 1.02)	252	1.01 (0.98; 1.03)	1.01 (0.98; 1.05)	26	1.02 (0.95; 1.10)	0.98 (0.88; 1.09)
Daily mean, time lag 1	458	0.99 (0.98; 1.01)	1.01 (0.99; 1.04)	250	1.00 (0.97; 1.02)	1.01 (0.98; 1.05)	26	1.04 (0.96; 1.12)	1.01 (0.91; 1.12)
Daily mean, time lag 2	444	1.00 (0.99; 1.02)	1.01 (0.98; 1.03)	243	1.00 (0.97; 1.03)	1.01 (0.98; 1.05)	23	1.06 (0.98; 1.13)	1.05 (0.93; 1.18)
Two-day daily mean, time lags 0 and 1	458	1.00 (0.98; 1.02)	1.00 (0.98; 1.03)	244	1.00 (0.98; 1.03)	1.01 (0.98; 1.05)	25	1.03 (0.95; 1.12)	0.98 (0.87; 1.10)
Three-day daily mean, time lags 0, 1, 2	458	1.00 (0.98; 1.02)	1.01 (0.98; 1.04)	230	1.00 (0.97; 1.03)	1.01 (0.97; 1.06)	22	1.05 (0.95; 1.16)	0.98 (0.84; 1.15)

95% CI: confidence interval of 95%; ppb: parts per billion; OR: odds ratio

1 OR estimated on basis of 13 health regions; case days were those associated with three or four reference days and for which we had ozone concentration estimates on case days and reference days

2 OR expressed for each 1 ppb increase in estimated tropospheric ozone concentrations

3 Sectors where most work done outdoors: *Agriculture; Forestry and logging; Construction; Mining, quarrying, and oil and gas extraction; Transportation and warehousing*

4 Adjusted for mean daily temperature, estimated the same day as tropospheric ozone levels

6. DISCUSSION

The main objective of this study was to estimate the association between daily numbers of occupational injuries accepted for compensation, including heat-related health problems and work-related accidents, and daily outdoor temperature in summer. The study also sought to explore the relationship between daily numbers of accepted claims for acute respiratory illnesses and daily ground-level ozone concentrations, whether outdoor temperature is considered or not.

6.1 Effect of Outdoor Temperature

6.1.1 Occupational Injuries

6.1.1.1 Heat-Related Health Problems

For all regions combined, we estimated a 42% increase (95% CI: 33%–55%) in the daily number of accepted injuries for health problems in connection with overexposure to heat, for each 1°C increase in maximum daily temperature. These results are consistent with the findings presented in State of Knowledge (section 2) and suggest that outdoor heat could be associated with an increase in the occurrence of heat-related illnesses in Quebec, even at temperatures that are not extreme.

More specifically, the risk functions presented in our study are similar to those reported for illnesses associated with heat exposure by the Florida Department of Health, with a 20%-to-60% daily increase in the risk of injury for every 1°C increase in maximum temperature.

Our study also highlighted a delayed effect (maximum temperature at time lags 1 and 2), as well as a cumulative effect (mean of maximum temperatures over two or three days, time lags 0–1 and 0–2), on the daily number of occupational injuries for heat-related illnesses. A delayed effect of temperature was also reported by the Florida Department of Health (time lag 1 only estimated), and these results are in line with the conclusions of a recent review of the literature on the association between ambient temperature and morbidity (for several nonspecific diagnoses), which found that most studies reported harmful effects of temperature, in the general population, up to three days after exposure (Ye *et al.*, 2012).

6.1.1.2 Work-related Accidents

For all regions combined, we calculated a 0.2% increase (95% CI: 0.2%–0.3%) in the daily number of accepted work-related accidents for every 1°C increase in maximum daily temperature. These results, which suggest that outdoor heat could be associated with an increased incidence of work-related accidents in Quebec, are also consistent with the state of knowledge presented in section 2.

The risk functions developed here are similar to those reported by Xiang *et al.* (2014b) for work-related accident claims accepted for compensation in Australia (0.2% daily increase in accidents for each 1°C increase in maximum daily temperature). However, the authors reported this increase for maximum temperatures ranging from 14.2°C to 37.7°C, while our study's temperature range was −7.8°C to 37.3°C, although injuries occurred above 5°C.

Maximum daily temperature did not seem to have a delayed effect on work-related accidents, but a slight two- or three-day cumulative effect (time lags 0–1 and 0–2) is possible. Xiang *et al.* (2014b) did not find any delayed effect above threshold temperatures, all higher than 31.8°C.

6.1.2 Vulnerable Groups

Another objective of this study was to identify subpopulations, industries and occupations at the greatest risk in Quebec. Below we discuss differences in health risks related to sex, age group and major industry sector and between manual occupational categories and mixed and non-manual categories.

6.1.2.1 Sex and Age

The risk estimates for health problems in connection with overexposure to heat were similar for men and women, while for work-related accidents, the risks were statistically higher for men. This difference was also noted by Xiang *et al.* (2014b). The difference in the breakdown of workers by sex and industry is likely one of the explanations for this finding. In Quebec, men make up almost 70% of the workforce in *Agriculture*, *Forestry*, *Fishing*, *Mining and oil and gas extraction* and *Construction*, whereas women are to be found more in sectors where most work is done indoors, namely *Educational services* and *Health care and social assistance* (Vézina *et al.*, 2011).

When differences between age groups were considered, we also obtained similar risk estimates for health problems in connection with overexposure to heat; for work-related accidents, risk estimates were statistically different between age groups, and risks were higher among young workers (ages 15–24) than among older ones. These findings are also in line with the literature, which also reports an increased risk of heat-related illnesses and work-related accidents among young people during periods of high heat (Bonauto *et al.*, 2007; Fogleman *et al.*, 2005; Maeda *et al.*, 2006; Xiang *et al.*, 2014b; Fortune *et al.*, 2013).

A number of factors, including lack of experience, training and competency, as well as being assigned to tasks or jobs that are more hazardous, may explain this increase (Xiang *et al.*, 2014b; CDC 2010). In our study, it is possible that the low number of accepted injuries by region for heat-related illnesses may have limited the possibility of observing differences between age groups. However, the six workers who died from hyperthermia during the study period all had at least one aggravating factor and five were under age 45 (CSST, 2002a, 2002b, 2003a, 2003b, 2004, 2006). The aggravating factors, commonly reported in the literature (CDC, 2008; Mirabelli and Richardson, 2005), included obesity, taking medication, poor knowledge of the language used in the workplace and a workload varying between average and high.

6.1.2.2 Industries

Variations in daily accepted injury counts and in associations with temperature were observed among industries. Due to our small sample, no risk function by industry for heat-related health problems could be calculated. We did note, however, that some sectors—*Forestry*, *Fishing*, *Mining*, *Public administration* and *Construction*—had the highest rates of claims accepted for compensation for heat-related health problems (data not presented). These same industries were also identified in a U.S. study conducted in the state of Washington (Bonauto *et al.*, 2007) as having the highest rates of claims accepted for heat-related health problems, which were defined similarly. The occupations most commonly associated with heat-related health problems in our study (labourers and materials-handling personnel, including those in metals processing, firefighting and truck driving) were the same as those cited in Bonauto *et al.* (2007). Furthermore, a recent descriptive study on occupational health claims for heat-related illnesses in Ontario showed that employees in *Manufacturing*, *Government service*, *Construction* and the *Public sector* had the highest rates of heat-related lost-time claims among all injuries (Fortune *et al.*, 2013).

For work-related accidents, we noted significant associations with temperature for some industries where most work is done outdoors, which is consistent with the results of Xiang *et al.* (2014b). These associations can also be found in sectors where work is done indoors, which suggests that outdoor temperature could contribute to the heat stress suffered by workers exposed to the residual heat of industrial processes, as well as by workers whose work environment lacks measures designed to reduce heat exposure, such as in textile mills, smelters and kitchens.

Last, risk estimates by occupational category of physical workload (manual or mixed and non-manual) within the same industry suggest that the effect of outdoor heat on work-related accidents varies in relation to the physical workload, but not uniformly. For example, the only statistically significant risk estimates within industries where work is done outdoors were found for the non-manual (e.g., managers in construction or agriculture, scientists in agriculture or geology, agricultural engineers) and mixed occupational categories (e.g., land surveyors, foremen/women in construction, agriculture or forestry, taxi drivers). We did not find any published papers on this topic, but it is possible that these occupations may involve more complex psychomotor tasks, the performance of which, according to Jay and Kenny (2010), might be more affected by exposure to heat than less complex tasks would, which could increase the accident risk. It is also possible that these occupations, which partly require doing work indoors (possibly in an air-conditioned environment), do not allow workers to become sufficiently acclimatized to heat (Yamazaki, 2013). More research is needed into the interrelations between physical workload and the effect of heat on occupational health.

The effects of heat on activities, performance and productivity are complex, and exposure to heat can have beneficial or harmful effects. For instance, working in hot conditions can cause fatigue and reduced alertness, leading indirectly to unsafe behaviour. Work in a hot environment also means sweating a lot more, which can affect dexterity. Conversely, it is also plausible that heat may have a beneficial effect on performance, given the increase in blood flow to the muscles and greater alertness due to heat stress that stimulates a person's attention and movements (Parsons, 2003).

6.1.3 Temperature Parameters

Modelling the association using wet temperature, rather than dry temperature with an adjustment for relative humidity, gave different results depending on the type of injury studied. Wet temperature produced a slightly higher IRR for heat-related health problems, whereas there was no difference in effect on IRRs for work-related accidents between dry temperature and wet temperature. We did not find any studies that compared illness or accident risk estimates calculated using these two ways of measuring temperature (dry or wet thermometer). As a result, it is hard to say which measurement method is the more sensitive, a point stressed by Ye *et al.* (2012), who note the lack of consensus about the sensitivity of various means of measuring temperature.

Some authors (Barnett *et al.*, 2010, Lippmann *et al.*, 2013) argue that measurements for a given health effect should be selected on the basis of data quality, completeness and coverage. In occupational health, wet-bulb globe temperature, or WBGT, is the most common temperature index used around the world (Parsons, 2003). Based on humidity, wind speed and air temperature, as well as on human solar radiation exposure, this index is the most inclusive indicator of heat stress (Health Canada, 2011); we feel that using it in our analyses would have given us a more accurate picture of the effect of temperature on workers. The index is not measured routinely by Environment Canada, however, and could not be calculated based on the data we had available for this study. Future research could further explore the influence of relative humidity on the relationship between temperature and occupational injuries, for instance by using relative humidity at the time when maximum temperatures occur.

6.2 Effect of Tropospheric Ozone

6.2.1 Acute Respiratory Illnesses

The non-adjusted relationships between daily tropospheric ozone concentration and acute respiratory illnesses among workers in industries where most work is done outdoors, though positive, were not statistically significant. This positive association, seen only among workers in these industries, could be due to the fact that they are more exposed to air pollutants than employees who work indoors.

These inconclusive results may in part be explained by the lack of specificity in the definition of acute respiratory illnesses, the lack of precision in the estimation of worker exposure and the low number of occupational injuries (and case days). In the few papers that have reported positive associations between ground-level ozone concentrations and certain respiratory effects on workers, the reduction in pulmonary functions was assessed precisely by means of spirometry (Chan and Wu, 2005; Brauer *et al.*, 1996; Brauer and Brook, 1997; Thaller *et al.*, 2008) or by means of questionnaires on specific symptoms (e.g., rhinitis) where worker exposure was assessed individually through personal sampling (Karakatsani *et al.*, 2009).

6.2.2 Adjustment for Temperature

For the same reasons, it is also impossible to draw any conclusions about the adjustment of the models with ozone using mean daily temperature, nor about the potential interaction between temperature and tropospheric ozone. Adjusting the model for maximum temperature changed the IRRs unsystematically, with decreases and increases depending on the study periods and industry sectors in question.

The respiratory effects of simultaneous exposure to heat and ozone have not been studied in depth, either among workers or in the general population, and conclusions are inconsistent (Reid *et al.*, 2012). It has nevertheless been documented that a toxicological interaction could occur as a result of simultaneous exposure. Heat causes a number of physiological reactions, including an increase in the ventilation rate, which at the same time causes the volume of inhaled air and the dose of ozone reaching the respiratory tract to rise. (For a review of the effects of the physiological changes associated with heat stress, see Truchon *et al.*, 2013.)

6.3 Methodological Issues

This study has a number of limitations related, in particular, to the data sources used and, for some stratified analyses, to the small sample sizes. These limitations are associated with a lack of precision that is impossible to quantify, but that does not prevent careful interpretation of results that may be useful for the purposes of monitoring and forecasting climate-related effects.

6.3.1 Use of Occupational Injuries Database

While the use of an occupational injury compensation administrative database allowed us to determine, for instance, the nature, event or exposure and source of the injuries accepted for compensation, it did not provide a sufficient level of detail for studying certain specific injuries. This may have led to some injuries being classified incorrectly. Nevertheless, one clear advantage of the CSST’s injury classification system, based directly on standard CSA Z-795, is that it remained virtually unchanged throughout the period covered by our study.

The case files contained in this type of administrative database concern only injuries reported to the CSST and for which it accepted compensation claims; the problem of the underreporting of occupational injuries in this type of database is known and has been examined in detail in several studies (Shannon and Lowe, 2002; Biddle *et al.*, 1998). In addition, some industries where most work is done outdoors and that were targeted in our study, such as *Agriculture*, *Forestry*, *Fishing* and *Construction*, are known for their low reporting rates (Fan *et al.*, 2006). It is therefore possible that the associations found in these industries underestimate the actual risk of occupational injury related to temperature increases.

A third limitation has to do with the lack of precision about the place where workers were exposed. The database does not contain any precise geographic information about the place where the occupational injury occurred. The only geographic information it provides is the postal code of the establishment with which the worker was associated at the time of the accident, and this postal code is used to link with the temperature and tropospheric ozone concentration databases. It is possible that some workers may have suffered occupational injuries at places other than their employer's listed establishment, and this fact was not taken into consideration in the analyses. These classification errors are probably more frequent in industries where employees are on the road (e.g., transportation) and in those where work is sometimes performed far from the employer's establishment (e.g., forestry).

Last, it was impossible with the data available to know whether the injuries occurred indoors or outdoors and whether the workers affected had been exposed to a source of heat other than the weather (e.g., smelter or fire). We have attempted to mitigate this inadequacy in the data by presenting industries where most work is done outdoors separately from those where most is done indoors (Table 5). It is hard to estimate the magnitude and direction of the effect resulting from this imperfect grouping.

Even though there are hard-to-quantify limitations to the use of occupational injury data, many researchers consider such data to be an important source for health and safety monitoring (Utterback *et al.*, 2012).

6.3.2 Temperature, Humidity and Tropospheric Ozone Concentration Data

An additional limitation associated with the measurement of exposure to maximum temperatures concerns the ecological nature of the estimates: data from one weather station per health region were used to estimate the temperature associated with each injury, since the local temperature at the employer's establishment or even that associated with a given postal code was not known. Even though these stations were identified beforehand by Environment Canada experts as being representative of their region's temperature, they may not adequately represent more localized weather conditions.

As mentioned earlier, the WBGT index would have been the best indicator of heat stress to use in connection with work, as it takes into account humidity, wind speed and air temperature, as well as solar radiation. However, it is not measured routinely by Environment Canada. We therefore decided to use the maximum temperature between 9 a.m. and 5 p.m., adjusting imperfectly for the degree of humidity with the highest hourly relative humidity reading over the same time period. No data were available on wind speed or sunshine at the work location. As a result, heat stress estimates are not precise.

Mean daily tropospheric ozone concentrations were obtained not directly from data collected at a weather station, but by means of a spatiotemporal forecasting model. This model, developed from sample data from some 50 Quebec weather stations, offered the advantage of being able to forecast expected ozone concentrations on a geographically smaller scale (delimited by postal code) than a health region. Nevertheless, these exposure estimates are still ecological, on a large geographic scale, and cannot be as precise as individual measurements.

6.3.3 Statistical Modelling

The regression models used to describe the association between temperature and occupational injuries needed to be adjusted for variations in the number of workers at risk of injury. We had data on the number of workers by region, but without distinction by sex or age group; we therefore had to use provincial (rather than regional) estimates of the monthly number of workers in these stratified analyses. As the breakdown of the labour force by age and by sex may differ in some regions in relation to the province as a whole, we conducted sensitivity analyses by omitting the offset variable (adjustment factor) representing the population at risk in the regression model. The risk estimates obtained were very similar, which suggests that the effect of this factor is negligible within the framework of these analyses where there is relatively little variation in population size. Sensitivity analyses were also conducted for sectors where the offset variable for the population of workers at risk was the regional monthly number of workers for several industries combined (see the Method section) and similar conclusions were reached with respect to this adjustment.

Modelling risk functions based on data from an urban region and then applying these models to all regions may constitute another limitation. To determine the impact on the accuracy of the models, we carried out sensitivity analyses on heat-related health problems and work-related accidents. Risk functions were therefore developed for two rural regions having a larger proportion of workers in *Agriculture*, *Forestry*, *Mining*, *Fishing* and *Oil and gas extraction*. The risk functions for one of the two regions were identical to those developed for Montreal. The functions obtained for the other region differed in terms of the modelling of the “year” variable (best fit with a cubic spline according to the likelihood ratio test) and in terms of a statistically significant interaction between temperature and humidity (the latter cancelling out the effect of temperature when the interaction term was added to the model). Given that the parameter used for relative humidity was not optimal, we could not draw any conclusions as to whether a real interaction between temperature and humidity existed or not.

Last, in the models describing the associations between temperature and accepted occupational injuries, we modelled the variable “temperature” by means of a no-threshold log-linear model, as natural cubic splines did not allow the best fit for these relationships. In the literature, a number of forms of risk function linking temperature and worker morbidity (Florida Department of Health, 2012) or work-related accidents (Knapik *et al.*, 2001; Fogleman *et al.*, 2005; Morabito *et al.*, 2006) are documented (e.g., linear, V-shaped, J-shaped). These different forms of relationship may be explained by the range and units of the temperature index used, as well as by the health effect and industrial sector studied. In our study, it is possible that the associations between temperature and accepted occupational injuries are not linear, and that the lack of precision of exposure measurements and health effects prevented other forms of risk function from being identified.

7. CONCLUSION

This study has shown a positive association between an increase of daily outdoor temperatures and the estimated daily risk of not only heat-related health problems, but also work-related accidents, which had not yet been documented in Quebec. The strength of these associations varies with worker age, industrial sector and occupational category, and exposure to a few hot days in a row seems to have a cumulative effect on the risk of heat-related illnesses. The results of this study suggest that occupational injury data could serve as sentinel indicators for identifying subgroups of workers at greater risk of suffering the effects of summer heat.

A positive association between acute respiratory illnesses and estimated ozone concentrations can be seen, but the low statistical power of the study prevents drawing any firm conclusions in this regard. Furthermore, predicted climate trends suggest a possible increase in the concentrations of other outdoor air pollutants, including particulates of all sizes, volatile organic compounds, pollens and other airborne allergens (moulds, spores and mycotoxins) (Institut national de santé publique du Québec [INSPQ], 2012), in the coming decades (Desjarlais *et al.*, 2010; IPCC, 2014). It is already known that atmospheric pollution increases the risks of a wide range of diseases, including lung and heart diseases, and it was recently classified as a known lung carcinogen in humans (World Health Organization [WHO], 2013). Future investigations should focus on better characterizing worker exposure to various atmospheric pollutants, especially among the most exposed workers, who spend long periods outdoors performing tasks that demand considerable physical exertion.

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APPENDIX 1

Development of a Spatiotemporal Model for Predicting Ozone Concentrations in Quebec

The model was developed in two stages.

First, a land-use mixed-effects regression model, the objective of which was to predict ozone concentrations in Quebec based on data from some 50 sampling stations in the air quality monitoring program run by the Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs (MDDEFP) from 1990 to 2009, was developed using a number of georeferenced variables, including temperature, precipitation, day of the year, year, estimated density of road traffic and latitude. When compared with real concentrations measured at sampling stations, this model had an R^2 of 0.466 and a standard error (root-mean-square error) of 8.747 ppb.

Next, the Bayesian maximum entropy method was used to incorporate the recorded data (i.e., the data from 1990 to 2009 from the sampling stations in the MDDEFP's air quality monitoring program) and the estimated information (estimates and uncertainties of the land-use mixed-effects regression model) in order to calculate a weighting associated with each of the concentrations measured at the sampling stations. This method produced an estimated exposure in terms of probability at all points of the area studied. When compared with the actual concentrations measured at the sampling stations, the final model, the estimates of which were used to determine worker exposure, had an R^2 of 0.653 and a standard error (root-mean-square error) of 7.06 ppb.

Further information about the modelling of Quebecers' environmental exposure to tropospheric ozone can be found in Adam-Poupart *et al.*, 2013 and 2014.

APPENDIX 2

Table A-1 – Mean and range of maximum daily temperatures and mean daily concentrations of tropospheric ozone (May to September, 1998–2010)

	Maximum daily temperature (°C)	Daily ozone concentration (ppb)
	Mean (range)	**Mean (range)**
Bas-Saint-Laurent	19.4 (0.7; 34.3)	29.3 (22.3; 36.8)
Saguenay–Lac-Saint-Jean	20.1 (1.8; 37.0)	30.4 (22.8; 39.6)
Capitale-Nationale	21.1 (2.6; 33.9)	27.8 (13.8; 44.4)
Mauricie et Centre-du-Québec	20.8 (4.4; 33.4)	26.2 (15.5; 47.5)
Estrie	21.5 (4.0; 33.8)	27.9 (15.8; 40.1)
Montreal	22.5 (4.8; 35.1)	26.3 (7.8; 50.3)
Outaouais	21.3 (2.3; 34.9)	26.9 (11.7; 50.1)
Abitibi-Témiscamingue	19.7 (−1.7; 35.9)	25.3 (16.1; 37.0)
Côte-Nord	16.8 (1.3; 30.1)	–
Nord-du-Québec	15.5 (−7.8; 37.3)	–
Gaspésie–Îles-de-la-Madeleine	15.0 (1.6; 29.7)	–
Chaudière-Appalaches	20.9 (2.2; 33.6)	33.1 (23.5; 40.5)
Laval	22.5 (4.8; 35.1)	26.4 (14.3; 39.6)
Lanaudière	22.5 (3.8; 34.5)	28.2 (15.7; 53.9)
Laurentides	21.5 (2.2; 35.6)	32.7 (15.0; 46.2)
Montérégie	22.6 (4.2; 34.7)	31.8 (13.9; 59.8)
All regions combined	20.2 (−7.8; 37.3)	28.5 (7.8; 59.8)

ppb: parts per billion

APPENDIX 3

Table A-2 – Sociodemographic characteristics of workers who had heat-related health problems, work-related accidents or acute respiratory illnesses (May to September)

	Heat-related health problems (1998–2010)		Work-related accidents (2003–2010)		Acute respiratory illnesses[1] (1998–2010)	
	Number	%	Number	%	Number	%
Total	259	100	374,078	100	458	100
Sex						
Women	45	17.4	110,844	29.6	197	43.0
Men	214	82.6	263,234	70.4	261	57.0
Age						
15–24	35	13.5	59,668	16.0	51	11.1
25–44	149	57.5	178,441	47.7	246	53.7
45 or older	75	29.0	135,969	36.3	161	35.2
Industrial sector (2003–2010)[2]						
Agriculture	4	2.2	4,054	1.1	7	2.8
Forestry and logging	8	4.5	3,504	0.9	0	0
Mining, quarrying, and oil and gas extraction	3	1.7	3,751	1.0	1	0.4
Fishing, hunting and trapping	0	0	222	0.1	0	0
Construction	19	10.7	29,784	8.0	11	4.4
Manufacturing	53	29.8	107,940	28.9	78	31.0
Utilities	0	0	1,418	0.4	2	0.8
Wholesale and retail trade	8	4.5	50,159	13.4	26	10.3
Transportation and warehousing	6	3.4	20,603	5.5	7	2.8
Information and cultural industries; Arts, entertainment and recreation	4	2.2	6,988	1.9	2	0.8
Professional, scientific and technical services	3	1.7	2,652	0.7	5	2.0
Business services, building-related services and other support services	12	6.7	15,732	4.2	10	4.0
Health care and social assistance	7	3.9	48,576	13.0	62	24.6
Educational services	0	0	9,360	2.5	11	4.4
Finance, insurance, real estate, leasing	0	0	4,615	1.2	3	1.2
Accommodation and food services	1	0.6	17,543	4.7	5	2.0
Other services – except public administration	4	2.2	11,959	3.2	4	1.6
Public administration	37	20.8	21,152	5.7	8	3.2
Not classified	9	5.1	14,066	3.8	10	4.0

[1] Acute respiratory illnesses for which a tropospheric ozone concentration was estimated.

[2] The CSST has been using the NAICS classification only since 2003; the number of accepted injuries for health problems in connection with overexposure to heat between 2003 and 2010 was 178, while for acute respiratory illnesses it was 252. Work-related accidents were considered for the period from 2003 to 2010 only, as discussed in section 5.2.2.

Table A-3 – Time-related characteristics of heat-related health problems, work-related accidents and acute respiratory illnesses (May to September)

	Heat-related health problems (1998–2010)		Work-related accidents (2003–2010)		Acute respiratory illnesses[1] (1998–2010)	
	Number	**%**	**Number**	**%**	**Number**	**%**
Day of the week						
Monday	46	17.8	73,475	19.6	98	21.4
Tuesday	68	26.3	74,988	20.0	95	20.7
Wednesday	65	25.1	71,126	19.0	88	19.2
Thursday	34	13.1	66,038	17.7	79	17.2
Friday	32	12.4	52,236	14.0	61	13.3
Saturday	5	1.9	19,885	5.3	13	2.8
Sunday	9	3.5	16,330	4.4	24	5.2
Month						
May	14	5.4	74,617	19.9	118	25.8
June	58	22.4	72,142	19.3	87	19.0
July	101	39.0	69,225	18.5	63	13.8
August	71	27.4	79,542	21.3	100	21.8
September	15	5.8	78,552	21.0	90	19.7
Year						
1998	10	3.9			59	12.9
1999	9	3.5			33	7.2
2000	4	1.5			41	9.0
2001	28	10.8			48	10.5
2002	30	11.6			25	5.5
2003	25	9.7	54,901	14.7	45	9.8
2004	16	6.2	53,612	14.3	32	7.0
2005	42	16.2	51,424	13.7	30	6.6
2006	16	6.2	49,552	13.2	30	6.6
2007	17	6.6	45,757	12.2	27	5.9
2008	10	3.9	43,004	11.5	27	5.9
2009	8	3.1	38,120	10.2	41	9.0
2010	44	17.0	37,708	10.1	20	4.4
Public holiday						
Yes	3	1.2	4,603	1.2	5	1.1
No	256	98.8	369,475	98.8	453	98.9
Construction industry vacation						
Yes	35	13.5	27,859	7.4	22	4.8
No	224	86.5	346,219	92.6	426	93.0

[1] Acute respiratory illnesses for which a tropospheric ozone concentration was estimated.

Table A-4 – Characteristics (nature and event or exposure) of accepted injuries

a) Injuries accepted for compensation for heat-related health problems (1998–2010)

	Heat-related health problems	
	Number	**%**
Total	259	100
Nature		
Effects of heat and light, unspecified	7	2.7
Heat stroke	14	5.4
Heat syncope	38[1]	14.7
Multiple effects of heat and light	4[1]	1.5
Effects of heat and light, n.e.c.	196[2]	75.7
Event or exposure		
Contact with temperature extremes, unspecified	244	94.2
Exposure to air pressure change, unspecified	1	0.4
Unknown, cannot be classified	14	5.4

n.e.c.: not elsewhere classified

[1] Includes one fatality

2 Includes four fatalities

b) Work-related accidents (2003–2010)

	Work-related accidents	
	Number	**%**
Total	374,078	100.0
Nature		
Sprain or strain	141,750	37.9
Bruises, contusions	43,429	11.6
Open wounds, unspecified and n.e.c.	36,919	9.9
Nature not coded	27,376	7.3
Musculoskeletal system and connective tissue diseases and disorders (except back)	26,673	7.1
Fractures	22,565	6.0
Other illness	15,906	4.3
Dorsopathies, unspecified and n.e.c.	9,317	2.5
Multiple traumatic injuries and disorders	8,530	2.3
Burns	8,016	2.1
Surface wounds andbruises	6,408	1.7
Unknown nature	6,076	1.6
Conjunctivitis – non-viral	6,050	1.6
Foreign bodies	5,537	1.5
Mental disorder or syndrome	3,976	1.1
Pain (except back pain)	3,873	1.0
Other injuries	1,504	0.4
Ear disorder	173	0.0
Event or exposure		
Transportation accidents	5,848	1.6
Fall; slip, trip, loss of balance without fall	57,709	15.4
Contact with objects and equipment, unspecified and n.e.c.	114,472	30.6
Exposure to harmful substances or environments, unspecified and n.e.c.	18,748	5.0
Overexertion, repetitive motion and other bodily reactions[1]	138,496	37.0
Other events or exposures and unknown	38,805	10.4

n.e.c.: not elsewhere classified

[1] "Other bodily reactions" refer to reactions other than slipping or tripping without falling, due to free movement of the body having caused stress or strain on a part of the body.

c) Acute respiratory illnesses[1] (1998–2010)

	Acute respiratory illness	
	Number	**%**
Total	458	100.0
Nature		
Respiratory system diseases, unspecified	16	3.5
Acute respiratory infections	58	12.7
Other diseases of upper respiratory tract, unspecified	6	1.3
Allergic rhinitis	12	2.6
Chronic conditions of upper respiratory tract	10	2.2
Other diseases of upper respiratory tract, n.e.c.	10	2.2
Pneumonia, influenza, unspecified	1	0.2
Pneumonia	12	2.6
Influenza	33	7.2
Legionnaires’ disease	3	0.7
Pneumonia, influenza, n.e.c.	11	2.4
Chronic obstructive pulmonary disease and allied conditions, unspecified	4	0.9
Bronchitis	34	7.4
Emphysema	1	0.2
Extrinsic asthma	116	25.3
Extrinsic allergic alveolitis or pneumonitis (including farmers’ lung, bagassosis)	2	0.4
Chronic obstructive lung disease (COLD)	3	0.7
Chronic obstructive pulmonary disease and allied conditions, n.e.c.	17	3.7
Asbestosis	4	0.9
Silicosis	1	0.2
Berylliosis	1	0.2
Pneumoconiosis, n.e.c.	1	0.2
Byssinosis	2	0.4
Metal fume fever	4	0.9
Pneumonopathy, n.e.c.	1	0.2
Pneumonitis, n.e.c.	10	2.2
Pulmonary edema	3	0.7
Pulmonary fibrosis, n.e.c.	1	0.2
Reactive airway dysfunction syndrome (RADS)	44	9.6
Other respiratory system diseases, n.e.c.	37	8.1
Event or exposure		
Other events or exposures	3	0.7
Contact with skin, or other exposed tissue	15	3.3
Overexertion, n.e.c.	1	0.2
Bodily conditions, n.e.c.	2	0.4
Exposure to harmful substances or environments, unspecified	18	3.9
Exposure to caustic, noxious, or allergenic substances, n.e.c.	71	15.5
Exposure to caustic, noxious, or allergenic substances, unspecified	77	16.8
Exposure to harmful substances or environments, n.e.c.	59	12.9
Inhalation in enclosed, restricted, or confined space	40	8.7
Inhalation in open or nonconfined space	67	14.6
Inhalation of substance, unspecified	92	20.1
Cannot be classified, unknown	10	2.2
Body reaction and exertion, n.e.c.	3	0.7

n.e.c.: not elsewhere classified

[1] Acute respiratory illnesses for which a tropospheric *ozone* concentration was estimated.

APPENDIX 4

Table A-5 – Mean daily count of heat-related health problems and work-related accidents and incidence rate ratio associated with a 1°C increase in maximum temperature (May to September)

	Health problem in connection with overexposure to heat (1998–2010)			Work-related accident (2003–2010)		
	Mean daily count (range)	**IRR[1]**	**95% CI**	**Mean daily count (range)**	**IRR[1]**	**95% CI**
Bas-Saint-Laurent	0.004 (0; 2)	1.165	0.885–1.532	8.44 (0; 25)	1.000	0.996–1.005
Saguenay–Lac-Saint-Jean	0.011 (0; 1)	1.171	1.062–1.291	11.53 (0; 37)	1.001	0.997–1.005
Capitale-Nationale	0.007 (0; 2)	1.428	1.214–1.680	30.15 (3; 69)	1.002	0.999–1.005
Mauricie et Centre-du-Québec	0.011 (0; 2)	1.280	1.099–1.490	18.85 (0; 53)	1.007	1.003–1.011
Estrie[2]	0.006 (0; 1)	1.397	1.131–1.726	12.22 (0; 37)	1.005	1.000–1.009
Montreal	0.030 (0; 4)	1.482	1.360–1.614	85.48 (14; 175)	1.002	1.001–1.004
Outaouais[2]	0.003 (0; 1)	1.751	1.000–3.065	7.51 (0; 24)	1.003	0.998–1.008
Abitibi-Témiscamingue[2]	0.002 (0; 1)	1.348	1.057–1.720	6.18 (0; 19)	1.004	0.999–1.009
Côte-Nord	0.004 (0; 1)	1.448	1.152–1.821	4.61 (0; 14)	1.004	0.996–1.011
Nord-du-Québec	0	0	0	0.46 (0; 5)	0.999	0.982–1.017
Gaspésie–Îles-de-la-Madeleine	0.003 (0; 1)	1.546	1.091–2.191	3.36 (0; 13)	0.991	0.980–1.002
Chaudière-Appalaches	0.009 (0; 2)	1.413	1.227–1.627	20.53 (0; 55)	1.002	0.999–1.005
Laval	0.008 (0; 2)	1.754	1.419–2.168	14.64 (0; 40)	1.005	1.001–1.009
Lanaudière	0.011 (0; 6)	1.816	1.450–2.274	13.83 (0; 37)	1.000	0.996–1.003
Laurentides	0.005 (0; 1)	1.313	1.092–1.579	17.96 (0; 46)	1.003	1.000–1.006
Montérégie	0.020 (0; 2)	1.553	1.394–1.730	49.86 (3; 113)	1.002	1.000–1.004
All health regions[3]	0.130 (0; 10)	1.405[3]	1.350–1.464	19.10 (0; 175)	1.002	1.002–1.003

95% CI: confidence interval of 95%; IRR: incidence rate ratio

1 IRR estimated by negative binomial regression, adjusted for day of the week, month, year, construction industry vacation, public holidays and relative humidity.

2 For health problems in connection with overexposure to heat, the IRRs for the Estrie, Outaouais and Abitibi-Témiscamingue regions were estimated using Poisson regressions.

3 For health problems in connection with overexposure to heat, the overall IRR was estimated on the basis of 15 health regions (i.e., excluding Nord-du-Québec).