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Summer outdoor temperature and occupational heat-related illnesses in Quebec (Canada)

Ariane Adam-Poupart [a], Audrey Smargiassi [a,b], Marc-Antoine Busque [c], Patrice Duguay [c], Michel Fournier [d], Joseph Zayed [a,c], France Labrèche [a,c,*]

[a] Department of Environmental and Occupational Health, School of Public Health, Université de Montréal, Montreal, QC, Canada
[b] Institut national de santé publique du Québec (INSPQ), Montreal, QC, Canada
[c] Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montreal, QC, Canada
[d] Direction de santé publique, Agence de la santé et des services sociaux de Montréal, Montreal, QC, Canada

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ABSTRACT

Background: Predicted rise in global mean temperature and intensification of heat waves associated with climate change present an increasing challenge for occupational health and safety. Although important scientific knowledge has been gathered on the health effects of heat, very few studies have focused on quantifying the association between outdoor heat and mortality or morbidity among workers.
Objective: To quantify the association between occupational heat-related illnesses and exposure to summer outdoor temperatures.
Methods: We modeled 259 heat-related illnesses compensated by the Workers' Compensation Board of Quebec between May and September, from 1998 to 2010, with maximum daily summer outdoor temperatures in 16 health regions of Quebec (Canada) using generalized linear models with negative binomial distributions, and estimated the pooled effect sizes for all regions combined, by sex and age groups, and for different time lags with random-effect models for meta-analyses.
Results: The mean daily compensation count was 0.13 for all regions of Quebec combined. The relationship between daily counts of compensations and maximum daily temperatures was log-linear; the pooled incidence rate ratio (IRR) of daily heat-related compensations per 1 °C increase in daily maximum temperatures was 1.419 (95% CI 1.326 to 1.520). Associations were similar for men and women and by age groups. Increases in daily maximum temperatures at lags 1 and 2 and for two and three-day lag averages were also associated with increases in daily counts of compensations (IRRs of 1.206 to 1.471 for every 1 °C increase in temperature).
Conclusion: This study is the first to quantify the association between occupational heat-related illnesses and exposure to summer temperatures in Canada. The model (risk function) developed in this study could be useful to improve the assessment of future impacts of predicted summer outdoor temperatures on workers and vulnerable groups, particularly in colder temperate zones.

1. Introduction

Climate changes are undeniable and their potential impacts on human health are becoming increasingly important among scientific concerns and public health policies. Climate scenarios project an increase in global mean temperature and in the frequency and intensity of heat waves over most areas around the world in the near future (IPCC, 2013, 2014).

Several epidemiological studies have been conducted on the effects of heat on mortality and morbidity in the general population (Basu, 2009; Ye et al., 2012). These studies have usually shown a non-linear increase in mortality and morbidity, over a city-specific summer temperature threshold. With global warming, heat exposure may present an increasing challenge for public health.

Heat exposure is also associated with health issues among workers. During the 2003 and 2006 heat waves in France, 15 and 8 deaths caused by hyperthermia were reported among workers, respectively (INRS, 2009; Buisson, 2009), while in the United States, 423 deaths were attributed to heat stroke in the workplace between 1992 and 2006 (CDC, 2008). Industrial sectors with

Abbreviations: CCDO, Canadian Classification Dictionary of Occupations; CI, Confidence interval; IRR, Incidence rate ratio; NAICS, North American Industrial Classification System; WCB, Workers' Compensation Board.

* Corresponding author at: IRSST, 505, de Maisonneuve Blvd West, Montreal (Quebec) Canada, H3A 3C2.
E-mail address: labreche.france@irsst.qc.ca (F. Labrèche).

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outdoor working activities, such as construction, agriculture, forestry, fishing, hunting and public services, present higher risks of death on hot days (Buisson, 2009; CDC, 2008; INRS, 2009). Descriptive morbidity studies, carried out on the working population of Washington State between 1995 and 2005 (Bonauto et al., 2007), and on working populations of the mining and the forestry sectors (Donoghue et al., 2000, 2004; Maeda et al., 2006), reported higher incidence of heat-related illnesses during the warmer months of the year and in specific occupations and/or sub-sectors.

Although important scientific knowledge has been gathered on the health effects of heat among workers (for a review, Jay and Kenny, 2010), very few studies have focused on quantifying the association between outdoor heat and heat illnesses. The risk function for the association between average summer temperatures and the number of occupational heat-related deaths was estimated in two studies; in the United States, the risk of on-duty coronary heart disease mortality among firefighters was not associated with increasing temperatures during months with average temperatures above 5 °C, between 1994 and 2004 (Mbanu et al., 2007), while in the whole working population of North Carolina between 1977 and 2001, the rate of heat-related death increased by 37% for each 1 °F increase (corresponding to approximately 77% per 1 °C increase) in average summer temperatures (Mirabelli and Richardson, 2005). In addition, only one pilot study, carried out by the Florida Department of Health (2012) between 2005 and 2009, reported a quantitative relationship between average summer temperatures and heat-related hospitalizations and emergency department visits, where cases were stratified in occupational and non-occupational groups. In this study, incidence rate ratios of 1.62 to 3.58 for every 5 °F increase (corresponding approximately to incidence rate ratios – IRRs - of 1.20 to 1.60 for every 1 °C increase) in daily maximum temperatures were calculated during the summer months in three different areas of the State.

Thus, there is evidence that outdoor heat may produce heat-related illnesses among workers, but these associations are still little explored. The aims of this study are to quantify the association between occupational heat-related compensations and exposure to summer outdoor temperature in Quebec (Canada).

2. Methods

The study analyzed the relationship between daily counts of compensations for heat-related illnesses and daily temperatures for all regions of Quebec (Canada) from May 1st to September 30th of each year between 1998 and 2010. These months cover the period when hot days may happen in Quebec, and the years of study were chosen according to availability of data. The study period consisted in 1989 days over the 13 years, and a total of 31,824 days-regions for analytical purposes (1989 days*16 health regions).

2.1. Compensation data

Compensations for heat-related illnesses were identified from a database of the Workers' Compensation Board (WCB) of Quebec. The WCB is the exclusive provider of compensations for employment injuries and illnesses in Quebec for persons who do work for an employer for remuneration. A few exceptions to this mandatory insurance provision exist in certain circumstances when work is done for the federal government, or for self-employed independent operators. The WCB covers 93% of the Quebec province workforce (AWCBC, 2013).

2.2. Study population

In the WCB database, all injuries are coded according to the nature of injury (i.e. physical characteristic of the injury) according to the Canadian Standards Association, Standard Z795. Compensations with any of the following nature codes were retained for the study period: 07200-Effects of heat or light, 07210-Heat stroke, 07220-Heat syncope, 07280-Multiple effects of heat or light, 07290-Effects of heat or light (not elsewhere classified) including heat-related fatigue and edema. Compensations for contact with hot objects or substances as events leading to the injury were excluded. To avoid misclassification, only compensations for acute heat exposure were retained for analyses. Case recurrence was verified and no claimant was compensated more than once for the same injury within 30 days.

Data obtained for each compensation included the claimant's date of birth and sex, the date of injury, the six-digit postal code of the employer establishment's location, the nature of injury, the North American Industrial Classification System (NAICS) code assigned to the employer's record, and the Canadian Classification Dictionary of Occupations (CCDO) code assigned to the claimant's occupation. When the postal code of the establishment's location was missing or erroneous (less than 7%), the postal code of the regional WCB office was used.

The establishment's postal code was used to classify each claim within one of the 16 health regions of Quebec (see Fig. 1 for health region names) and daily counts of heat-related injury compensations were calculated per health region, stratified by sex, age categories as found in the Labor Force Survey of Statistics Canada (15–24 years old, 25–44 years old, and 45 years old and more), and NAICS sector.

2.3. Meteorological data

Hourly meteorological data were obtained from the Environment Canada Data Access Integration Team (http://loki.qc.ec.gc.ca/DAI/DAI-e.html). One monitoring station, previously identified by Environment Canada as representative of the weather of each region (Martel et al., 2010), was chosen for each health region. The daily maximum hourly values in the 8-hour period between 9h00 and 17h00 were retained for dry bulb temperatures (°C), wet bulb temperatures (°C) and relative humidity (%). Wet bulb temperatures are obtained with a thermometer whose bulb is covered by a wet cloth and differ from the dry bulb temperatures by an amount that depends on the moisture content of the air (EC, 2013). The maximum daily temperature exposure was considered constant among the working population within each health region. For statistical analyses, days with less than 75% of meteorological data (2.5% of 31,824 days-regions) were excluded.

2.4. Statistical analyses

A risk function for the association between daily compensation counts and daily hourly maximum temperatures was developed using a generalized linear model with negative binomial regression for the health region with the highest compensation counts (i.e. Montreal, the largest urban area of the province). To control for temporal trends (i.e. seasonality, long term time trend), the model was adjusted for day of the week, month, year and for the two-week holiday of the construction sector (statutory in Quebec) and public holiday periods. Daily maximum relative humidity in the 8-hour period was also included in the model, since the increase in body temperature induced by heat exposure may be accelerated with high relative humidity (Parsons, 2003; Tanaka, 2007).

In an attempt to find a compromise between providing adequate adjustments and leaving sufficient information from which to estimate the temperature effect, the impact of including the year, relative humidity and temperature as linear or cubic spline function variables was assessed with the likelihood ratio test. In addition, the statistical interaction between temperature and relative humidity was verified. As an offset in the model, the monthly regional working population estimate obtained from the Labor Force Survey of Statistics Canada (table CANSIM 282–0001, http://www5.statcan.gc.ca/cansim/) was used. The model developed for the health region of Montreal is the following:

$$\begin{aligned}\text{Ln}\,[E(\text{Yt})] = {} & \ln\,(\textit{Monthly working population estimates}) \\ & + \beta_0 + \beta_{1-6}\textit{Day of the week} + \beta_{7-10}\textit{Month} + \beta_{11}\textit{Year} \\ & + \beta_{12}\textit{Construction sector holiday} + \beta_{13}\textit{Public holiday} \\ & + \beta_{14}\textit{Daily maximum relative humidity over } 8h \\ & + \beta_{15}\textit{Daily maximum temperature over } 8h + \varepsilon\end{aligned}$$

where E(Yt) is the expected daily counts of heat-related compensations.

This model (same variables with no spline function) was then applied to the other health regions of Quebec. Thus, IRRs per 1 °C increase, and 95% confidence intervals (CI) per health region were obtained. In very few cases the negative binomial model did not converge and when data were not over-dispersed, Poisson regression was used instead. Pooled effect sizes for Quebec (all health regions combined) were estimated using a random effect model with the method of DerSimonian and Laird for meta-analysis.

The same analyses produced estimates after stratification by sex and age group. The pooled estimates were based on the regions where heat-related compensations were found in every sex/age groups and for which models converged with negative binomial or Poisson regressions using the same adjustment variables. For these analyses, the monthly working population estimates of each subgroup for the whole province were used as the offset, because this information was not available at a regional level. The Cochran Q test was used to assess differences of effect of temperatures between sex and age subgroups (Kaufman and MacLehose, 2013).

As the studied outcomes include health effects that could be related to longer term exposure, such as heat-related fatigue and edema, time-lag phenomena were explored by looking at the association between heat-related compensations and the weather conditions of the current day (lag 0), and also with weather conditions of the two previous days (lag 1 and lag 2). The cumulative effect of two-day (mean

	Mean daily maximum temperature °C (range)	Heat related compensations			
		Number of compensations (%)	Mean daily count (range)	Mean (range) daily rate per 1 000 000	IRR (95% CI)
Bas-Saint-Laurent	19.4 (0.7;34.3)	8 (3.1)	0.004 (0; 2)	0.04 (0.00; 20.88)	1.165 (0.885; 1.532)
Saguenay-Lac-Saint-Jean	20.1 (1.8;37.0)	21 (8.1)	0.011 (0; 1)	0.09 (0.00; 8.44)	1.171 (1.062; 1.291)
Capitale Nationale	21.1 (2.6;33.9)	14 (5.4)	0.007 (0; 2)	0.02 (0.00; 5.31)	1.428 (1.214; 1.680)
Mauricie et Centre du Québec	20.8 (4.4;33.4)	22 (8.5)	0.011 (0; 2)	0.05 (0.00; 8.88)	1.280 (1.099; 1.490)
Estrie	21.5 (4.0;33.8)	11 (4.2)	0.006 (0; 1)	0.04 (0.00; 7.39)	1.397 (1.131; 1.726)
Montréal	22.5 (4.8;35.1)	60 (23.2)	0,030 (0; 4)	0.03 (0.00; 4.32)	1.482 (1.360; 1.614)
Outaouais	21.3 (2.3;34.9)	5 (1.9)	0.003 (0; 1)	0.01 (0.00; 6.67)	1.751 (1.000; 3.065)
Abitibi- Témiscamingue	19.7 (-1,7;35.9)	4 (1.5)	0.002 (0; 1)	0.03 (0.00; 15.72)	1.348 (1.057; 1.720)
Côte-Nord	16.8 (1.3;30,1)	7 (2.7)	0.004 (0; 1)	0.06 (0.00; 18.73)	1.448 (1.152; 1.821)
Gaspésie-îles-de-la-Madeleine	15.0 (1,6; 29,7)	5 (1.9)	0.003 (0; 1)	0.07 (0.00; 28.41)	1.546 (1.091; 2.191)
Chaudière-Appalache	20.9 (2.2; 33.6)	18 (6.9)	0.009 (0; 2)	0.04 (0.00; 9.02)	1.413 (1.227; 1.627)
Laval	22.5 (4.8; 35,1)	15 (5.8)	0.008 (0; 2)	0.04 (0.00;10.69)	1.754 (1.419; 2.168)
Lanaudière	22.5 (3.8; 34,5)	21 (8.1)	0.011 (0; 6)	0.05 (0.00;33.20)	1.816 (1.450; (2.274)
Laurentides	21.5 (2.2; 35.6)	9 (3.5)	0.005 (0; 1)	0.02 (0.00;4.58)	1.313 (1.092; 1.579)
Montérégie	22.6 (4.2; 34,7)	39 (15.1)	0.020 (0; 2)	0.03 (0.00;2.91)	1.553 (1.394; 1.730)
Overall (16 health regions) [c]	20.2 (-7.8; 37.3)	259 (100)	0.130 (0; 10)	0.04 (0.00; 2.49)	1.419 (1.326-1.520)

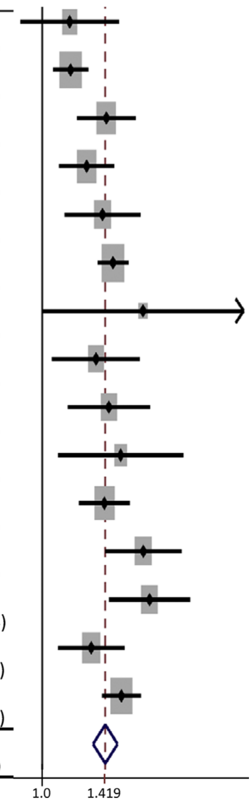

Fig. 1. Daily maximum temperatures, heat-related compensations, estimated incidence rate ratios associated with a 1 °C increase in daily maximum temperatures, by health regions. Quebec, Canada (May–September, 1998–2010).

of lags 0–1) and three-day (mean of lags 0–1–2) averages of daily maximum temperatures was also estimated.

Finally, the effect of using another temperature metric (wet bulb temperature) in the model was assessed. All analyses were conducted with Stata version 12.1.

3. Results

3.1. Descriptive results

There were 259 heat-related illnesses (including 6 fatalities) compensated for acute heat exposure during the 1989 days from 1998 to 2010 (May-Sept) in Quebec for an average annual population of 3.7 million workers (Fig. 1). The heat-related illnesses that were compensated occurred in 15 out of the 16 health regions; 44% of these were in the greater area of Montreal with a working population of approximately 1.78 million. For the whole province of Quebec, the daily number of heat-related compensations ranged from 0 to 6 per region and the average daily number was 0.13 while the daily rates per million workers ranged from 0.01 to 0.09 with an overall rate of 0.04.

Meteorological data are shown in Fig. 1. The regional averages of daily maximum temperatures ranged from −7.8 to 37.3 °C with an overall mean of 20.2 °C. The regional averages of daily maxima had also large ranges for relative humidity (22% to 100%) and wet bulb temperatures (−8.8 to 29.4 °C). As expected, May and September were the coldest months of the study period (average maxima of 15.9 °C and 18.4 °C), while July and August were the warmest months (average maxima of 23.3 °C and 22.7 °C).

The patterns of daily temperatures and of daily compensation counts over time, and characteristics of the compensations are presented as supplemental material (see Table S1 and Figure S1). Most compensated heat-related illnesses occurred on week days and during the months of July and August. Most compensated claimants were male (82.6%), aged 25–44 years old and working in the Manufacturing (29.8%), Public Administration (20.8%) or Construction (10.7%) sectors, doing work as laborers (in material handling: 32% and metal processing: 4%), firefighters (11%) and truck drivers (4%). Overall, the "effects of heat or light (not elsewhere classified)" was the most frequent nature of injury, followed by heat syncopes. Six heat-related deaths (all men) occurred during the study period and were classified as one heat syncope and five deaths following effects of heat or light.

3.2. Exposure-response relationship

Over the study period, no heat-related outcome was compensated for days when the daily maximum temperature was below 10 °C, while 63.0% of heat-related illnesses occurred on days when this temperature was between 10 and 30 °C. More than a third of the illnesses occurred when the maximum temperature was higher than 30 °C (3% of the 31,824 days-regions of the study period) and fatalities occurred on days when the daily maximum temperature was above 27 °C. For the Montreal region, the linear model relating daily heat-related compensation counts and daily maximum temperatures and the model with spline functions were similar (likelihood ratio test: χ^2 (1 df)=0.91; P-value=0.339). Therefore, the relation between the daily heat-related compensation counts and daily maximum temperatures was modeled as linear for all regions.

There was a statistically significant effect of daily maximum temperatures on heat-related compensations in 14 of the 15 health regions where claims were accepted. For all regions combined, an increase of approximately 42% (pooled estimate) in daily heat-related compensations was observed with an increase of 1 °C in daily maximum temperatures (IRR 1.419, 95% CI 1.326–1.520; see Fig. 1).

The incidence rate ratio of compensations per 1 °C increase was higher among women than among men, but the 95% CIs overlapped considerably and the difference was not statistically significant (heterogeneity χ^2 (1 df): 0.96; $p=0.327$). The risk ratio was also slightly higher for workers aged 25–44 years old compared to other age groups, but again, the risk ratios were not statistically different between subgroups (heterogeneity χ^2 (2 df): 0.18; $p=0.916$). Increases in daily maximum temperatures were associated with increases in daily heat-related compensations for lag 0, lag 1 and lag 2 and for two and three-day lag averages. Risks were similar across lags and multiple lag averages, with the strongest effects observed with two and three-day lag averages (Table 1). It was not possible to calculate specific IRRs per industrial sector due to the very low compensation counts in each health region.

When using a different temperature metric, the wet bulb temperature, the estimated IRR for all regions combined was 1.486 (95% CI 1.411–1.567), suggesting a stronger effect of temperature as measured with the wet bulb compared to the dry bulb metric adjusted for relative humidity.

4. Discussion

We observed a positive log-linear relationship between the daily maximum temperatures and heat-related compensations for 15 health regions of Quebec (one health region had no such compensation during the study period). With a mean daily count of 0.13 compensation, a 42% increase in daily heat-related compensations counts was observed with each increase of 1 °C in daily maximum temperatures for all health regions combined.

These results cannot be directly compared to the risk functions developed to quantify the association between outdoor heat and mortality (Mbanu et al., 2007; Mirabelli and Richardson, 2005), because our model was developed essentially on non-fatal heat illnesses (6 fatalities for 259 heat illnesses). Comparison of our results with those of studies on morbidity performed in other latitudes may also be difficult, as hot temperature thresholds for morbidity appear to vary by location (Ye et al., 2012). Nonetheless, the influence of latitude may be limited and may not importantly limit the generalizability of our results as the latter are comparable to those of the Florida Department of Health (2012), located more than 10° latitude further south. In their pilot study using an approach similar to ours (i.e. generalized linear model, with a Poisson distribution and adjustments for temporal trends), the Florida Department reported incidence rate ratios for occupational heat-related hospitalizations or emergency department visits of 1.62 to 3.58 for every 5 °F increase (corresponding approximately to IRRs of 1.20 to 1.60 for every 1 °C increase) in daily maximum temperatures at lag 0 in three different areas of the State during the summer months. In comparison, we obtained an IRR of 1.42 per 1 °C increase at lag 0.

Moreover, the Florida researchers calculated incidence rate ratios of 1.69 to 3.40 for every 5 °F increase (corresponding approximately to IRRs of 1.21 to 1.57 for every 1 °C increase) at lag 1 during the summer months. In this pilot study, authors did not model the temperature effect at lag 2, but reported that among models which included various numbers of lag days (lag 0; lags 0–1 to lag 0–5), the models that had the best fit were the ones including the temperature of the current and previous days (lags 0–1 and lags 0–2). In our study, daily maximum temperatures were associated with increases in IRRs on the day of the illness, on the following days (lags 1 and 2) and also with increase of two and three-day average temperatures; the temperature effects of those multiple lag days were even stronger compared to the model at lag 0 (Table 1). Overall, these findings suggest that heat-related illnesses may also develop over a number of days due to a delayed effect of heat exposure. In a recent review of epidemiological evidence on the relationship between ambient temperatures and morbidity (several nonspecific diagnoses), Ye et al. (2012) reported that the majority of studies on the relationship between ambient temperatures and nonspecific morbidity describe detrimental effects of temperatures on the same day or up to the following 3 days.

Regarding the effect of using several temperature metrics, we could not find a paper comparing risk estimates obtained from dry

Table 1
Daily compensations and estimated incidence rate ratios associated with a 1 °C increase by sex and age groups and for different time lags. [a,b] Quebec, Canada (May–September, 1998–2010).

Classification	Number of compensations n (%)	Mean daily count n (range)	IRR (95% CI)
Sex[c] and Age[d,e]			
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)
15–24 years old	35 (13.5)	0.02 (0;4)	1.436 (1.163, 1.772)
25–44 years old	149 (57.5)	0.07 (0;6)	1.462 (1.284, 1.665)
45 years old and more	75 (29.0)	0.04 (0; 3)	1.395 (1.162, 1.677)
Lag effects			
Lag 0	259 (100.0)	0.130 (0;10)	1.419 (1.326, 1.520)
Lag 1	259 (100.0)	0.130 (0;10)	1.322 (1.255, 1.392)
Lag 2	259 (100.0)	0.130 (0;10)	1.206 (1.161, 1.252)
2-day average (lag 0-lag 1)	259 (100.0)	0.130 (0;10)	1.471 (1.373, 1.576)
3-day average (lag0-lag1-lag2)	259 (100.0)	0.130 (0;10)	1.464 (1.376, 1.557)

IRR, incidence rate ratio; 95% CI: 95% confidence interval.

[a] Incidence rate ratios estimated for all health regions of Quebec combined (May–September, 1998–2010).

[b] Models estimated with binomial negative or Poisson regressions and adjusted for day of the week, month, year, public and construction sector holiday periods and relative humidity.

[c] Sex groups: IRRs estimated for 6 health regions (Saguenay, Estrie, Montréal, Chaudière-Appalaches, Laval, Montérégie) with heat-related compensations for men and women and in which models converged with negative binomial or Poisson regressions using the same adjustment variables.

[d] Age groups: IRRs estimated for 6 health regions (Saguenay, Estrie, Montréal, Lanaudiere, Laurentides, Montérégie) with heat-related compensations for every age group and in which models converged with negative binomial or Poisson regressions using the same adjustment variables.

[e] No statistically significant heterogeneity between sex or age groups.

bulb and wet bulb temperatures. In the Florida pilot study (2012), the estimated incidence rate ratios were lower when modeled with the maximum heat index only (IRRs of 1.16 to 2.11 for every 5 °F increase, corresponding approximately to IRRs of 1.06 to 1.32 for every 1 °C) as opposed to maximum temperatures; the heat index is not directly comparable to the wet bulb temperature in that it is derived from both dry bulb temperature and relative humidity. Nonetheless and in contrast, we found that the effect of the wet bulb temperatures (IRR 1.486) was larger than the effect of the dry bulb temperatures adjusted for relative humidity (IRR 1.419). This difference may be, at least partially, explained by various assumptions. The relationship of the wet bulb temperatures in our study was modeled log-linearly and the effect of the dry bulb temperatures was adjusted for relative humidity, while the Florida department of Health modeled the heat index relationship as quadratic, and the effect of temperature was estimated without adjustment for relative humidity. In the literature, there is no consensus regarding the effect of the choice of temperature metrics on temperature-health associations (Ye et al., 2012) and recent studies reported that the metric selection for a specific health outcome should be based on data quality, completeness and coverage (Lippmann et al., 2013).

As did the Florida researchers (2012), we used a log-linear relationship (linear model with Poisson distribution) to estimate the association between daily counts of heat-related compensations and daily maximum temperatures. It is in agreement with findings by Ye et al. (2012), who reported that studies focusing separately on associations during hot or cold seasons usually show a linear association between temperatures and morbidity.

4.1. Vulnerable subgroups

The risk ratio of compensation counts per 1 °C increase in maximum daily temperatures was not statistically different between women and men or between age subgroups. In occupational studies, higher risk of heat-related illnesses and work-related injuries are often reported among young workers (Bonauto et al., 2007; Maeda et al., 2006; Xiang et al., 2014; CDC, 2010), which can be attributed to various factors such as the lack of experience, training and skills and their assignment to more strenuous tasks or to jobs with increased hazards (Xiang et al., 2014; CDC, 2010). Our findings are however based on very low compensation numbers obtained in the 15–24 age group ($n=35$), and this explains that not all regions contributed cases to calculate the age-specific IRRs (only 6 health regions). The relative lack of sensitivity of compensation data to capture heat-related illnesses could also have contributed to discrepancies between study findings, as well as a different distribution of age groups by industry. For the 8 years of study, six fatalities were compensated during the study period, all of them were male workers (5 out of 6 were less than 44 years old) who performed medium to heavy workload in outdoor activities (agriculture, $n=1$; forestry, $n=2$; landscaping, $n=1$; construction, $n=2$). Risk factors identified during the WCB inquests into these deaths (Commission de la santé et de la sécurité du travail du Québec, 2002a, 2002b, 2003a, 2003b, 2004, 2006), such as the lack of training and experience, obesity, use of medication, and incomplete knowledge of the main language used in the workplace, are commonly reported in the literature (CDC, 2008; Mirabelli and Richardson, 2005).

4.2. Methodological considerations

This study has some limitations. First, the daily counts of heat-related illnesses are probably underestimated: a large number of workers at risk for heat-related illnesses are employed in sectors that are well known for underreporting injuries, such as agriculture, forestry, fishing and construction (Fan et al., 2006). Second, the small numbers of regional daily counts of compensations dictate cautious interpretation of the results, especially in sex or age-stratified analyses. Third, misclassification of heat exposure is very likely. The employer's location (postal code) was used to link heat-related illnesses and temperatures and some workers may have suffered their heat-related illnesses at another location; this particularly concerns sectors where employees are on the road (e.g. transportation) or where the working activities take place far from the employer's location (e.g. forestry). Moreover, the database did not contain information on the working environment and some compensated injuries could have resulted from indoor heat exposure. Additional misclassification may have also resulted from the ecological nature of the temperature estimates: data from only one weather station was used to estimate the temperature per health region, instead of estimating local temperature at each employer's location. Even if these stations were previously identified by meteorological experts of Environment Canada as representative of the weather of a health region, and although they were used for health surveillance studies in Quebec (Martel et al., 2010; Lebel and Bustinza, 2011), they cannot capture conditions in microenvironments. Fourth, possible regional variations in the labor force during the study period may have influenced the results of the sex and age-stratified analyses, as the provincial monthly working population estimates of each group were used instead of region-specific estimates. Sensitivity analyses done without the offset gave very similar results, suggesting that the effect of the offset was negligible. Lastly, a limitation may arise from the fact that the models were developed based on data from an urban region. The adequacy of that model was verified by developing two additional models based on two rural health regions (i.e. with higher proportions of workers in agriculture and in forestry, fishing, mining, quarrying, oil and gas industries). One model was exactly the same as the urban one, while the other differed only by the modeling of the year variable (cubic spline provided a better fit according to the likelihood ratio test) and there was a significant interaction between temperature and humidity. Without the interaction term, the temperature effect remained the same, whereas with the interaction term, the temperature effect was negative and not statistically significant.

Despite some limitations, our study is the first in Canada that quantifies the association between occupational heat-related illnesses and exposure to summer ambient temperatures, using meteorological data linked to occupational compensation statistics. Results indicate a statistically significant increase in the number of heat-related illnesses with the increase of the maximum daily temperature. Recent evaluations for Quebec predict increases of average summer temperatures in the order of 1.6 to 3.0 °C by year 2050 (Ouranos, 2010). The model (risk function) developed in this study could be useful to improve the assessment of future impacts of predicted summer outdoor temperatures on workers and vulnerable groups, particularly in colder temperate zones.

If an health effects indicator as crude as compensation statistics can show measurable increments in risk with increasing maximum temperature, climate change effects will have to be closely monitored among workers.

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Ethical approval

The project received ethical approval from the Health Research Ethics Committee of the University of Montreal (Application number 12–606-CERES-D) and from the Commission de la santé et de la sécurité du travail, the worker compensation data custodian.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2014.07.018.

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