Association between air temperatures and occupational injuries: a case-crossover analysis using workers’ compensation claims data in the construction industries in Northern Italy

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Abstract. Background and Aims: The aim of this study was to evaluate the relationship between high air temperatures and occupational injuries (OIs) occurred in construction workers (CWs) from the Autonomous Province of Trento (APT). Material and Methods: Data about OIs for the APT from 2000 to 2013 occurring (N = 14,072) and daily weather were retrieved. On the basis of minimum (Tmin) and maximum (Tmax) values for air temperatures, assessed days were classified in “Neutral days” (Tmin > 0°, Tmax < 25°C), “Frost days” (Tmin < 0°C), “Summer days” (Tmax > 25°C), “Summer days/Tropical nights” (Tmax > 25°C, Tmin < 20°C), and Heat-Wave time period (i.e. 3 or more consecutive days with Tmax > 35°C). Daily average temperatures (Tday) were then categorized in 7 exposure groups (<5th, 5-9th, 10-24th, 25-74th, 75-89th, 90-94th and ≥95th percentiles). The risk of OIs was assessed as odds ratio (OR) calculated through a Poisson regression model. Results: Estimated incidence of OIs during the study period was 6.2 ± 3.1 events/day (2.8 injuries / 10,000 workers / day). The peak of OIs occurred during Heat-Wave time period (OR 1.200, 95%CI 1.104-1.304) on Summer days (OR 1.093, 95%CI 1.04-1.146) and in days characterized by Tday > 95th percentile (OR = 1.142, 95%CI 1.062 - 1.235). Colder days were seemingly associated with a protective effect (OR 0.892, 95%CI 0.831-0.957 for Frost days, and OR 0.854, 95%CI 0.746-0.978 for Tday < 5th percentile). Younger age groups were associated with increased risk for higher exposures. Conclusions: Presented findings recommend policymakers to develop appropriate procedures and guidelines, in particular aimed to improve the compliance of younger CWs towards severe-hot daily temperatures.

Keywords: construction workers, climate change, heat exposure, occupational injuries, hot weather, heat waves.
I. INTRODUCTION

During the last decades, climate changes have significantly affected both living and working environments (1-3). The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has estimated in 0.78°C the increase of the average global temperature between 2003 and 2012 (4), with an even higher risk for population exposed to Mediterranean-like climates (5-17). Because of a combination of external thermal environment, heat sources in the workplace, and internal heat generation by physical activity associated with strenuous muscular work, climate changes and eventual heat exposure represent an even greater challenge to workers’ health and safety, especially in persons with pre-existing illnesses (2,7,18-28). The risk of heat-related health effects appears significantly increased in outdoors workers, including construction workers (CW), for several reasons (1,3,18,29-36). First and foremost, even though the mechanization of many tasks may reduce the strenuous physical labour carried out by CWs, many activities still require exhausting manual work, and extensive mechanization requires economic resources that are often beyond the financial capacity of many small companies (i.e. < 10 employees) (30,37,38). Second, due to the physical nature of construction industry, CWs usually perform a large share of their activities outdoors, poorly protected against meteorological factors such as extreme heat and solar radiation (30,39). Third, health and safety training in CWs are frequently inadequate, and again small companies are less likely to implement appropriate procedures and guidelines (30,32,37-40). Hence, many CWs may continue to work beyond a safe heat exposure limit as they are unaware of the risks associated with the heat exposure, or have inappropriate knowledge of the preventive measures, e.g. avoiding the hottest hours of the day for most strenuous physical exertion, or increasing the water intake during the Heat waves (HWs).

Increased environmental temperatures may affect health and safety of CWs also as an increased risk for occupational injuries (OIs) (1,29,30,41,42). As high temperatures can affect cognition, hamper concentration, reduce vigilance and increase fatigue, working during extreme warm weather would ultimately increase the risk of mistakes, accidents and injuries (18,35,36,42-44), especially in subjects who otherwise would spend little time outdoor, such as part-time or seasonal workers (29). Moreover, higher temperatures may force the workers to reduce the use of personal protective equipment (PPE), ultimately increasing the risk for OIs associated with the exposure to dusts and chemicals (1,3,18,29-36,41).

As climate change effects gradually progress, the importance of understanding the impact of hot climate on injuries in CWs and preventing them through appropriate preparedness and emergency response plans in the workplace becomes a growing challenge for occupational health and safety (1,3,18,24,29,32,35,36,42,45). The aim of this study was therefore to assess to what extent CWs have been impacted by hot weather in the Autonomous Province of Trento (APT).

II. METHODS

1. Settings. APT is located in the Italy’s North East, covers a total area of 6,214 km² (2,399 sq mi) and has a population of 537,416 habitants (2015 census). According to available labor force statistics, in the last decade construction industry employed around 9.2% of total, and 14.8% of male workforce (i.e. around 20,000 adult age subjects/year) (48,49).
2. Meteorological data. Meteorological data, including daily average (Tday), minimum (Tmin), maximum (Tmax) temperatures, as well as air relative humidity, atmospheric pressure, wind speed and solar irradiation for the study period were obtained from the Meteotrentino Service (http://www.meteotrentino.it/dati-meteo/info-dati.aspx?ID=3) of the APT. Meteotrentino Archive includes data from a total of 214 meteorological stations scattered over the provincial area, allowing to direct link geographical site of injury with air temperature at the time of the accident. As data about air relative humidity, wind speed and solar irradiation were not available for all meteorological stations, data from the nearest station at the time of the index injury were ultimately retrieved.

Exposure groups were defined as follows. As otherwise suggested (46), calendar days were categorized by Tmin and Tmax in: Frost days (i.e. days with Tmin < 0°C), Summer days (i.e. days with Tmax > 25°C), Summer days/Tropical Nights (i.e. days with Tmax > 25°C and Tmin > 20°C). Days not included in the aforementioned definition were classified as “Neutral days”. The whole observation period was then dichotomized as HW time period vs. non-HW time period. Currently, there is no universal definition of a HW, although it may be broadly defined as a prolonged period of excessive heat. In order to more easily compare our results with similar types of research, we have defined a HW event as a time period including at least 3 consecutive days with Tmax ≥ 35°C.

3. Occupational injuries. Data on compensation claims for OIs for all of APT from 01/01/2000 to 31/12/2013 were retrieved from the archive of the Operative Unit for Health and Safety in the Workplaces (UOPSAL, Italian acronym), the institutional service representing the local governmental structure for the management and prevention of OIs, occupational diseases, and work-related diseases in the workplaces. Available data were anonymized in order to include only age at the time of the event, sex, and country of birth, and incorporated reference to the geographical site (municipality-level detail) and calendar date of the events, the nature of injury, bodily location, mechanism, and agency of injury/disease. Retrieved OIs were then classified as: falls (in general), falls from height > 2 m, associated with manual handling, associated with the use of tools or machineries, following distraction and/or carelessness during usual tasks. As activities of the construction industry are clustered during the warm season, but diffusely performed across the calendar year, we retrieved all available injuries, and excluded all cases that occurred: (a) during winter (i.e. December 21st to March 20th); (b) in days characterized by rain or snow (arbitrary cut-off: 5 mm); (c) during weekends, long weekends, and holidays; (d) on the way to/from the workplace (in Italian, “in itinere”); (e) clearly indoors; Similarly, (f) injuries without information on the place of event were excluded from the analyses.

4. Ethics. The study included only a retrospective assessment of data available through an Institutional Database, and the analysis was performed as a part of the official duties of the Occupational Health and Safety Unit (UOPSAL). Personal data were restricted to information about the occupational injury, and were treated in order to guarantee the respect of privacy of the involved workers, as specifically stated by Italian Law n. 675 of 1996 about personal data protection. Therefore, the study did not require preliminary evaluation by the local Ethical Committee.

5. Statistical analysis. Continuous variables were tested for normal distribution (D’Agostino and Pearson omnibus normality test): where the corresponding p value was < 0.10, normality distribution was assumed as rejected and variables were compared through Mann-Whitney or Kruskal-Wallis test.
for multiple independent samples. On the other hand, variables passing the normality check (D’Agostino and Pearson p ≥ 0.10) were compared using the Student’s t-test or ANOVA, where appropriate. Daily rates of OIs were calculated for the study period, by year, by season, by calendar month, and eventually for the exposure groups as previously described. We assumed that the recorded events (i.e., OIs) were mutually independent, and although influenced by demographic factors and by the extent of the activities performed in that time period, eventually related to air temperatures. In order to adjust crude rates for factors having a presumptive effect on the outcome variable injury rate, Odds Ratios (ORs) with their respective 95% Confidence Intervals (95%CI) were calculated for all cases, for cases having a prognosis ≥ 40 days and with any long-term sequela, as well as by age groups (i.e. < 20 years, 20-29 years, 30-39 years, 40-49 years, ≥ 50 years) and by settings of the injury, through a Poisson regression model that included exposure categories as the effector variables, meteorological data (i.e. air relative humidity, atmospheric pressure, wind speed and solar irradiation) as covariates. In the analyses, reference categories were: “neutral days” and “non-HW time period”, when appropriate. All the analyses were performed in SPSS 25 (IBM Corp. Armonk, NY).

III. RESULTS

Overall, a total of 2,257 days were included in the analysis (44.1% of total observation period). The average Tday was 12.7°C (range -6.2°C to 29.9°C, median 13.1°C), and average values for Tmin and Tmax were 6.5°C (-10.5°C to 21.0°C) and 20.5°C (0.1°C to 41.2°C), respectively.

Table 1. Number and characteristics of workers’ compensation claims for acute work-related injuries in the construction industries, Autonomous Province of Trento (2000-2013).
A total of 246 days (10.9%) fulfilled the working definition of “Frost day”, whereas 1,161 (51.4%) were classified as “Summer days” and 15 (0.7%) as “Summer days/Tropical nights”. Eventually, 161 days were included in the HW definition (7.1%).

As shown in Table 1, a total of 20,724 OIs were initially retrieved: after exclusion criteria were applied, a total of 14,072 OIs were analysed: the majority of them occurred in CWs that were < 40 year-old at the time of the injury (61%; mean age 36.7 ± 11.4 years), and in subjects of Italian origin (77.3%). The final sample included 13,931 males (99.0%; mean age: 36.7 ± 11.4 years), and 141 females (1.0%; mean age: 36.6 ± 10.9 years), of similar age (p > 0.05). In 2,396 cases (17.0%), the occupational injury had a prognosis ≥ 40 days, with long-term sequelae in 12.9% of all cases. The majority of OIs included in the analyses occurred as falls (21.1%), with a third of them (6.6% of total sample) from height > 2 m, followed by OIs involving the use of tools and/or machineries (17.6%), distraction and/or carelessness during usual tasks (17.4%), and tasks requiring manual handling (6.1%).

Estimated incidence of OIs during the study period was 6.2 events by day (95%CI 6.1-6.4), with an estimated cumulative incidence of 3.1 OIs / 10,000 workers / day (95%CI 3.0-3.15). As shown in Table 2, daily rates of OIs were significantly higher in Summer days than in reference to Neutral ones (3.20, 95%CI 3.11-3.30 vs. 3.02, 95%CI 2.92-3.12), whereas a significantly lower rate was identified for Frost days (2.78, 95%CI 2.59-2.96). Similarly, higher rates for OIs were reported in days fulfilling the working definition of HW time-period (3.47, 95%CI 3.19-3.76 vs. 3.06, 95%CI 2.99-3.12 in non-HW time-period).

Table 2. Rates of occupational injuries (OIs) in the construction industries throughout the classification of reported days by meteorological data. All data are presented with their respective 95% Confidence Intervals.

<table>
<thead>
<tr>
<th>Classification of Reported Days</th>
<th>OIs (No./100,000 person-day)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral day (Tmin &gt; 0.0°, Tmax &lt; 25.0°)</td>
<td>3.02 (2.92; 3.12)</td>
<td>-</td>
</tr>
<tr>
<td>Frost days (Tmin &lt; 0.0°C)</td>
<td>2.78 (2.59; 2.96)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Summer days (Tmax ≥ 25.0°C)</td>
<td>3.20 (3.11; 3.30)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Summer days, tropical nights (Tmax ≥ 25.0°C, Tmin &gt; 20.0°C)</td>
<td>3.11 (2.02; 4.20)</td>
<td>0.917</td>
</tr>
<tr>
<td>Heat Waves (3 or more consecutive days with Tmax &gt; 35°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Included in Heat Wave definition</td>
<td>3.47 (3.19; 3.76)</td>
<td>0.006</td>
</tr>
<tr>
<td>Not included in Heat Wave definition</td>
<td>3.06 (2.99; 3.12)</td>
<td></td>
</tr>
</tbody>
</table>

A significantly higher risk for OIs in Summer days as well as in HW time-period was identified also in regression analysis (OR 1.200, 95%CI 1.104-1.304, and 1.093, 95%CI 1.042-1.146), and again Frost days were associated with a significantly reduced risk (OR 0.892, 95%CI 0.831-0.957), in particular for subjects 20-29 year-old (OR 0.822, 95%CI 0.712-0.951) and 30-39 year-old (0.779, 95%CI 0.680-0.891) (Table 3). However, when focusing on the severity of the OIs (i.e. prognosis ≥ 40 days, evidence of long-term sequelae), no significant difference was found.
Table 3. Risk of occupational injuries (OIs) in the construction industries, throughout the classification of calendar day by meteorological data. All data are presented as Odds Ratios with their respective 95% Confidence Intervals.

<table>
<thead>
<tr>
<th>Characteristics of the OIs</th>
<th>Heat Wave (3 or more consecutive days with Tmax &gt; 25°C)</th>
<th>Frost Days (Tmin &lt; 0°C)</th>
<th>Summer days (Tmax &gt; 25°C)</th>
<th>Summer days, Tropical nights (Tmax &gt; 25°C, Tmin &lt; 20°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cases</td>
<td>1.200 (1.104; 1.304)</td>
<td>0.892 (0.831; 0.957)</td>
<td>1.093 (1.042; 1.146)</td>
<td>1.083 (0.778; 1.454)</td>
</tr>
<tr>
<td>Only cases with prognosis ≥ 40 days</td>
<td>0.996 (0.804; 1.233)</td>
<td>1.121 (0.961; 1.307)</td>
<td>0.997 (0.891; 1.116)</td>
<td>0.585 (0.218; 1.568)</td>
</tr>
<tr>
<td>Only cases with long-term sequelae</td>
<td>1.016 (0.801; 1.288)</td>
<td>0.959 (0.800; 1.150)</td>
<td>1.005 (0.887; 1.139)</td>
<td>0.729 (0.272; 1.955)</td>
</tr>
<tr>
<td>Age groups</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>&lt; 20 years</td>
<td>2.089 (1.527; 2.858)</td>
<td>0.815 (0.575; 1.155)</td>
<td>1.302 (1.040; 1.630)</td>
<td>3.493 (1.417; 8.612)</td>
</tr>
<tr>
<td>20 – 29 years</td>
<td>1.225 (1.038; 1.446)</td>
<td>0.822 (0.712; 0.951)</td>
<td>1.048 (0.933; 1.152)</td>
<td>1.043 (0.558; 1.950)</td>
</tr>
<tr>
<td>30 – 39 years</td>
<td>1.176 (1.005; 1.375)</td>
<td>0.779 (0.680; 0.891)</td>
<td>1.065 (0.976; 1.162)</td>
<td>1.185 (0.684; 2.053)</td>
</tr>
<tr>
<td>40 – 49 years</td>
<td>1.200 (1.020; 1.413)</td>
<td>0.952 (0.829; 1.094)</td>
<td>1.134 (1.032; 1.246)</td>
<td>0.938 (0.485; 1.813)</td>
</tr>
<tr>
<td>≥ 50 years</td>
<td>0.974 (0.778; 1.220)</td>
<td>1.167 (0.986; 1.381)</td>
<td>1.107 (0.981; 1.249)</td>
<td>0.502 (0.161; 1.565)</td>
</tr>
<tr>
<td>Characteristics of the OIs</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Falls, in general</td>
<td>1.065 (0.896; 1.266)</td>
<td>1.010 (0.885; 1.152)</td>
<td>1.046 (0.950; 1.152)</td>
<td>1.074 (0.591; 1.952)</td>
</tr>
<tr>
<td>Falls from height &gt; 2 m</td>
<td>1.018 (0.741; 1.398)</td>
<td>0.899 (0.704; 1.147)</td>
<td>1.080 (0.910; 1.283)</td>
<td>0.649 (0.161; 2.617)</td>
</tr>
<tr>
<td>Distraction /carelessness during usual tasks</td>
<td>1.010 (0.838; 1.218)</td>
<td>1.178 (1.020; 1.359)</td>
<td>1.041 (0.939; 1.154)</td>
<td>1.030 (0.533; 1.993)</td>
</tr>
<tr>
<td>Use of tools/machineries</td>
<td>1.194 (0.987; 1.444)</td>
<td>0.756 (0.638; 0.896)</td>
<td>1.138 (1.037; 1.293)</td>
<td>1.534 (0.842; 2.794)</td>
</tr>
<tr>
<td>Manual handling</td>
<td>1.364 (1.023; 1.819)</td>
<td>0.876 (0.687; 1.116)</td>
<td>0.942 (0.796; 1.115)</td>
<td>1.588 (0.652; 3.866)</td>
</tr>
</tbody>
</table>

Days fulfilling HW, Summer day and Summer day/Tropical night definition were associated with a significantly higher risk of OIs in subjects < 20 year-old at the time of the event (OR 2.089, 95%CI 1.527-2.858; OR 1.302, 95%CI 1.040-1.630, and OR 3.493, 1.417-8.612, respectively), and the association between HW time-period and OIs remained statistically significant also for subjects < 40 year-old. Regarding the mechanism of the injuries, an increased risk was reported for distraction and/or carelessness during usual tasks in Frost days (OR 1.178, 95%CI 1.020-1.359), for handling of tools/machineries in Summer days (OR 1.158, 95%CI 1.037-1.293) and for manual handling during a HW time-period (OR 1.364, 95%CI 1.023-1.819), whereas a significantly reduced risk was identified for OIs associated with the handling of tools/machineries during Frost days.
In our retrospective study, we assessed whether climate might represent a significant effector on the risk for OIs, focusing on daily extremes (Tmin and Tmax). Eventually, we found a significantly increased risk of OIs for series of days with Tmax > 35°C (i.e. HW time-period), but also for days with a Tmax ≥ 25°C (i.e. Summer days) when compared with milder temperatures, and in both cases the outcome was particularly noticeable on younger workers. The latter were also affected by days characterized by very high Tmin (>20°C, i.e. “Summer days/Tropical nights”), although relatively rare (i.e. 0.7% of all observation period). However, as no association between most severe traumas and environmental exposures was identified, our data presumptively hint towards a significant role only for minor injuries, indirectly suggesting some kind of adaptation towards uncomfortable temperatures (18,35,36,42-44).

Despite a significant heterogeneity in the methodology of risk assessment, previous reports have frequently identified the highest risk for work-related accidents in days characterized by severe but not extreme thermal conditions, and days associated with either extreme hot or cold weather having lower incidence rates (i.e. “inverted U-shaped curve”) (29,42). Even though a retrospective study performed on the same regional settings and the same timeframe recently suggested that extreme rather than nearly extreme daily average temperatures may exert a detrimental effect on OIs for workers performing their tasks outdoors, such as agricultural workers, these results may explained as a sort of behavioral adaptation to severe climates. In other words, workers would avoid most strenuous activities during the hottest days and/or the hottest hours of the working day during the warm season and, similarly, coldest days of the cold season would be perceived as inappropriate to perform outdoor activities (29,43). Not coincidentally, in our sample colder days were both associated with a reduced risk for OI associated with the use of tools and machineries, and with an increased one for accidents characterized by distraction and/or carelessness during usual tasks, but the risks appeared unrelated with the severity of the traumas. Although our model deliberately excluded days characterized by significant rain and/or snow, it should also kept in mind that construction industry usually clusters its activities from March to October, in particular for tasks necessarily performed outdoors. As CWs often perform a large share of their daily tasks on unstable, irregular surfaces, we could assume such figures as a consequence of the deliberate avoiding of more dangerous tasks, in particular those performed on scaffolds and platforms, either as a shift towards safer activities or as a forced rest until a significant improvement of the weather (30,31,39,47). Similarly, as in our study the rates of OIs in subjects ≥50 year-old were somehow unaffected by extreme temperatures, we may understand such better performances as a kind of “healthy worker effect”, i.e. the consequence of the experience of the workers towards unfavorable working conditions, ultimately potentially dangerous tasks (47). The above construction may be therefore a corollary for both the increased rates we identified in younger age groups in unfavorable hot conditions, in particular for presumptively unexperienced subjects < 20 year-old. In other words, the reduced rates for OIs in colder climates possibly reflect a more accurate approach of CWs towards uncomfortable working conditions, whereas reduced incidence for colder but not extreme days.

However, it should be stressed that our study is affected by several limitations. Firstly, weather conditions such as radiant heat, air humidity, wind speed and solar irradiation, in a mountainous region such as APT, may strikingly fluctuate over a restricted area because of the altitude. (3,29,42,43) In other term, whereas an assessment at municipality level may guarantee a sufficient detail for air temperature,
in the settings of our survey it might be not so accurate for other factors (50,51). Moreover, as available data about air humidity, wind speed and solar irradiation are more diffusely scattered over the area of APT, their inclusion in the exposure assessment may have increased its inaccuracy.

Second, also the data regarding the work-related accidents are affected by some inaccuracies. Available information about occupational injuries were retrieved from an institutional database, whose content didn’t include either clinical data or an accurate description of the level of physical activity performed at the time of the event, the type of clothing, and hydration status, and these factors significantly affect the risk for heat related health effects (29,42).

In conclusion, our data suggest that extreme hot temperatures may be associated with increased risk of occupational injuries in the construction industries. Collectively, such results stress the importance for the active implementation of appropriate procedures and guidelines, in particular aimed to improve the compliance of younger workers towards severe-hot daily temperatures.
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