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The association between extreme weather conditions and work-related injuries and diseases. A systematic review of epidemiological studies

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Abstract

Introduction. The relationship between extreme temperature and population health has been well documented. Our objective was to assess the evidence supporting an association between extreme temperature and work related injuries.

Methods. We carried out a systematic search with no date limits using PubMed, the Cochrane central register of controlled trials, EMBASE, Web of Science and the internet sites of key organizations on environmental and occupational health and safety. Risk of bias was evaluated with Cochrane procedure.

Results. Among 270 studies selected at the first step, we analyzed 20 studies according to inclusion criteria (4 and 16 referring to extreme cold and heat temperature, respectively).

Discussion. Despite the relevance for policy makers and for occupational safety authorities, the associations between extreme temperature and work related injuries is seldom analyzed. The estimation of risk, the identification of specific jobs involved and the characterization of the complex mechanisms involved could help to define prevention measures.

Key words

- occupational health
- occupational injuries
- climate change
- environmental health
- temperature

BACKGROUND

Changes in many extreme weather and climate events have been observed progressively in the last decades. Some of these changes have been linked to human influences, including a decrease in cold and an increase in warm temperature extremes. The most recent Intergovernmental Panel on Climate Change (IPCC) reported that extreme weather events have become more frequent and intense in recent years [1].

The relationship between high temperatures, heat waves and population health has been well documented. Epidemiological evidence suggests that extremely hot weather contributes to excess morbidity and mortality, particularly among the elderly, patients suffering chronic diseases and under pharmacological therapies [2-6]. Epidemiological findings also suggest that cold temperatures affect mortality more indirectly than heat and by the means of longer exposures [7-9]. One of the most indisputable consequences of climate change is the increased frequency and intensity of heat waves. The number of deaths due to the 2003 heat wave in eight European countries was close to 35 000 people in three weeks [10, 11].

There has been a growing research concern in the literature about the impact of heat-related events on workers' health and safety in recent years, nonetheless the extent of effect on occupational safety and health of climate change is still under debate and largely unknown. Furthermore the evidences related to the categories of workers affected by heat (or cold) exposure remains controversial. Same evidences have been reported concerning hot. Workplace heat exposure can increase the risk of occupational injuries and accidents [12-16]. Short-term acute extreme heat exposure may disrupt core body temperature balance and result in heat-related illnesses. Adverse long-term health effects of chronic workplace heat exposure have also been reported. Heat gain can be a combination of heat from

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the external thermal environment and internal heat generation by metabolism associated with physical activity. In the workplace, there are two types of external heat exposure sources: weather-related and process-generated. With predicted increased heat waves with global warming, weather-related heat exposure is presenting an increasing challenge for occupational health and safety.

Recently two scientific reviews have demonstrated the association between intense and prolonged occupational exposure to heat temperature and health effect on workers such as dehydration and spasms, increased perceived fatigue and reduced productivity [17, 18]. Occupational exposure to cold temperature could increase cardiovascular and respiratory diseases risks, musculoskeletal and dermatologic disorders and could induce injuries related to hypothermia [19]. Specific individual (age, gender, health general conditions) and occupational (job type, seniority) factors were involved in risk of health effects due to both heat and cold temperature. Previous studies have shown that job categories majorly involved were construction sector, agriculture, waste management and disposal, steel workers and transport [12-16, 20, 21] but findings are still controversial and generally obtained in different observational conditions.

In this work we aimed to conduct a systematic review in order to assess and summarize the scientific evidence on the potential health impacts of occupational exposure to high or low extreme temperature. The purpose was to: i) examine the available published papers concerning the epidemiological associations between extreme weather and work-related injuries; ii) identify which industrial sectors, occupations, genders and age groups are more vulnerable to extreme weather, according to selected papers in order to provide evidence for policy makers and stakeholders involved in occupational safety and health. This could help in identifying evidence-based elements for the implementation of targeted public health interventions geared to increase adaptive capacity, through enhancing the level of awareness of heat/cold-related risks or to reduce susceptibility of workers.

MATERIALS AND METHODS

In the field of environmental health, research syntheses lag behind comprehensive, rigorous and transparent systematic review methods developed in clinical sciences. To close this gap, many researchers and international institutions show an increasing interest in applying these procedures to questions related to environmental health and to provide a reproducible framework to evaluate the quality of the evidence in the environmental field [22-26]. For this purpose we applied a systematic review methodology as a tool to synthesize findings from relevant studies. Such methods (which include a literature review with a well-defined research question, uses systematic and explicit methods to identify, select and appraise research, analyze data from selected studies, and , if possible, integrates results of chosen studies by a meta-analysis) already exist to evaluate clinical evidence [27, 28] for evidence-based decisions for health-care interventions.

For this review we included studies meeting the following eligibility criteria:

a. prospectively designed and controlled studies (including randomized controlled trials, non-randomized controlled trials), administrative cohort studies, case-control, case crossover, ecological correlational studies and ecological time series studies;
b. working population of all ages, sex and ethnic groups;
c. use of a defined, objective information source for high and low temperature (*e.g.* not obtained retrospectively from patient but measured from meteorological stations);
d. the outcome measure was overall mortality, any trauma or work-related injuries, morbidity (*e.g.* emergency visits for symptoms or signs related to heat or cold);
e. estimates of either odds, risk or hazard ratios or available data allowing for their calculation.

We considered only literature discussing studies on humans. Studies dealing with the synergistic effect of air pollution and temperature on the incidence of work-related injuries were also considered (*e.g.* effect of heat on low and high pollution days).

We excluded studies that did not report original results (reviews, letters, comments) or did not provide sufficient data (*e.g.* lack of information about the number of cases and controls or about the used method).

Exploratory studies, such as time-trend exploratory studies, were not included. Only etiologic studies are included.

Search methods for identification of studies

We carried out a systematic search to identify peer-reviewed, primary research papers. The following bibliographic databases were searched: PubMed (January 1966 to September 2014), the Cochrane Central Register of Controlled trials (CENTRAL, The Cochrane Library, September 2014), EMBASE (January 1974 to November 2014), and Web of Science (September 2014).

A specific search strategy were developed for each database used, accounting for differences in controlled vocabulary and syntax rules. *Table 1* give details of the search for MEDLINE.

We also searched the internet sites of key organizations on environmental area such as:

- Occupational Safety Health Agency (www.osha.gov/)
- European for Safety & Health Agency (https://osha.europa.eu/)
- WHO (www.who.int/en/)
- Centers for Disease Control and Prevention - CDC (www.cdc.gov/).

Data extraction and assessment of bias

Two authors independently screened titles and abstracts of studies obtained by the search strategy. Each potentially relevant study located in the search was obtained in full text and assessed for inclusion independently by two authors. In case of disagreement a third author was consulted.

A standardized data extraction form was used to col-

Table 1
Search strategy for MEDLINE complete (via EBSCO)

1.	TI Hot N2 temperature OR TI high N2 temperature OR TI summer N2 temperature OR TI extreme N2 temperature OR TI ambient N2 temperature OR AB Hot N2 temperature OR AB high N2 temperature OR AB summer N2 temperature OR AB extreme N2 temperature OR AB ambient N2 temperature
2.	TI heat N1 wave* OR AB heat N1 wave*
3.	TI heatwave* OR AB heatwave*
4.	MH "Hot temperature/adverse effect"
5.	#1 OR #2 OR #3 OR #4
6.	MH cold temperature
7.	TI cold N2 temperature OR TI low N2 temperature OR TI extreme N2 temperature OR TI outdoor N2 temperature OR AB cold N2 temperature OR AB low N2 temperature OR AB TI extreme N2 temperature OR AB outdoor N2 temperature
8.	#6 OR #7
9.	AB work* OR TI work*
10.	TI workplace OR AB workplace
11.	MH Workplace
12.	TI occupation* OR AB occupation*
13.	#9 OR #10 OR #11 OR #12
14.	MH animals NOT MH humans
15.	#5 AND #13
16.	#8 AND #13
17.	#15 NOT #14
18.	#16 NOT #14

lect data from each relevant study. Extracted information included:
- general study details (citation, study design);
- setting (size of the company, country, industry subsector, and trade and job);
- participant details, including key demographic characteristics;
- exposure measurement details;
- confounders variables considered;
- crude and adjusted outcome data;
- key elements for preventive measures (*e.g.* recommendations, advice for categories of workers) to translate into workers healthcare protocols.

For each included study we evaluated the methodological quality of the evidence assessing the risk of bias defined as characteristics of a study that can introduce a systematic error in the magnitude or direction of study findings [28]. We explored the potential risk of bias using the tool already developed by Johnson *et al*. 2014 [22] by adapting existing risk of bias guidance used to evaluate human studies in the clinical sciences: the Cochrane Collaboration's Risk of Bias tool [28] and the Agency for Healthcare Research and Quality's criteria [29]. Two authors independently assessed the following risk of bias:
- recruitment strategy;
- blinding;
- confounding;
- exposure assessment;
- outcome assessment;
- incomplete outcome data;
- selective outcome reporting;
- conflict of interest;
- other bias.

We graded each potential source of bias as high, low or unclear and provided a quote from the study report together with a justification for our judgment in the "Risk of bias" tables. We summarized in a graph the risk of bias judgements across different studies for each of the domains listed.

Data analysis

Considering the heterogeneity of the study design, outcome measures and participants included the studies we planned not to produce a pooled estimate, but to present a narrative summary of findings. The narrative report would classify and present studies according to type of exposure.

RESULTS

The present review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [30]. Our systematic review identified 270 potential articles. After duplicates were removed, 176 articles were further screened on title and abstract and 42 full texts retrieved. Finally, we found 8 papers that investigated extreme temperature-related illnesses including 2 papers [21, 31] that assessed the impact for heat and cold exposure both. *Figure 1* shows the study selection process. Of the 26 studies that met the inclusion criteria, we excluded 18 studies available on line (*Supplementary Materials*) from our review for a variety of reasons, primarily because they used a study design not considered in the review.

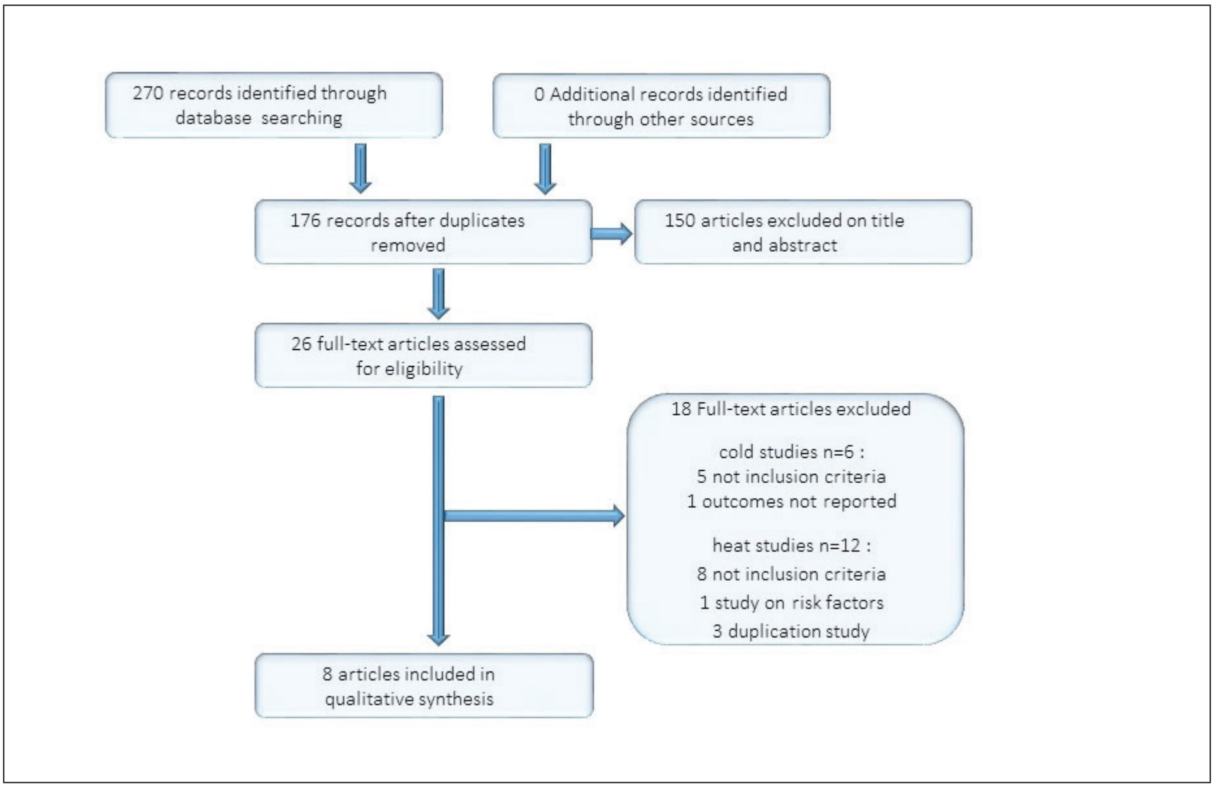

Figure 1
Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram.

Study characteristics

Table 2 provide an overview of the 8 eligible studies. All studies meeting the inclusion criteria were observational studies, five adopted an ecologic time series design [21, 31-34], two were correlational studies [35, 36], and one a case-control study [37]. Four studies took place in the United States [31, 32, 37, 36], two in Italy [21, 35], and in Australia [33, 34]. Time of publication ranged from 2000 to 2015.

The studies used daily maximum temperature [31-34, 36], daily mean temperature [21, 31], apparent temperature [35]. A study considered heat waves [33] as exposure variable and the study of Bell [36] considered cold days (<0 °F and 0-10 °F). Only two studies analyzed the dose-response relationship between temperature and the health outcomes finding a reversed U-shaped exposure-response relationship [34, 35], or linear relationship [32] or linear above/below a threshold [21, 31]. The same studies explored the delayed effect of temperature, with similar results of an acute effect (within 3 days) [21, 32, 34] for both high and low temperatures. The effect of high and low temperature and work injuries was studied through parametric and non parametric regression models (*i.e.* GEE, GAM, negative binomial regression) in six studies and through non parametric tests in one study [35]. A study [31] estimated the effect of high and low temperature through Bayesian analysis. A case control study [37] analyzed cases of heat-associated deaths registered in a local surveillance system to assess the risk of death in workers. Regression models were adjusted for other meteorological variables (barometric pressure, wind speed) and calendar factors (years, months, weekdays and holidays). None of the study included air pollution among potential confounders, except Fortune *et al.* [31]. A study [35] had a limited statistical power. In the study of Bell *et al.* [36] potential confounders were not taken into account.

Effect estimates were presented for work-related injuries in five studies [21,32-34,36] using workers' compensation databases while two study provided risk estimates of temperature-related morbidities such as emergency room visits and hospitalizations defined from administrative databases using the ICD-10 [31] and ICD-9 codes [35]. All studies, except Morabito *et al.* [35] and Fortune *et al.* [31], provided risk estimates by categories of workers (*i.e.* for working age, gender, occupational sectors, job activity, work location).

Tables 3a and 3b summarize the data reported studies characteristics.

Risk of bias assessment for individual studies

The risk of bias of the included studies was summarized in *Figure 2* and *Figure 3*. Given the nature of exposure and study design, we judged that for these eight studies the knowledge of exposure status (blinding) is not an element capable of introducing risk of bias. Four studies had a low risk of bias for recruitment since studies reported no main differences in terms of baseline characteristics among groups.

For all studies we assigned a low risk of bias related to incomplete outcome data, conflict of interest. All studies used routine administrative data which we assumed

Table 2
Overview of included studies

Source	Location	Years of study	Study design	Population
Adam-Poupart 2014 [32]	16 regions Quebec Canada	May and September 2003-2010	Ecologic Time series analysis: daily counts of compensations for work-related injuries and daily summer temperatures	N = 374 078 Work-related injuries compensation
Fortune 2014 [31]	Ontario Canada	1 January 2004-31December 2010	Ecologic time series analysis: to examine the associations between occupational, temperature-related emergency department visits and meteorological data	N = 171 463 occupational emergency department encounters
Morabito *et al.* 2014 [21]	Tuscany Italy	2003-2010	Ecologic time series analysis: to investigate short-term effect of high/low air temperature on outdoor occupational injuries	N = 162 399 outdoor occupational injuries
Xiang 2014a [33]	Adelaide Australia	1 July 2001- 30 June 2010 (only warm season)	Ecologic time series analysis: investigate the association between high temperature and work-related injuries during a 9-year period	N = 125 267 workers' compensation (summer only)
Xiang 2014b [34]	Adelaide Australia	July 2001-June 2010 (only warm season)	Ecologic time series analysis: investigate the association between heatwave and work-related injuries during a 9-year period	Workers' compensation claim N = 125 267
Petitti 2013 [37]	Arizona USA	1 January 2002-31 December 2009	Case control study	N = 444 cases of heat-associated deaths and 925 controls
Morabito *et al.* 2006 [35]	Florence, Prato Italy	June-September 1998-2003	Ecologic correlational study: analyze the relationship between hot weather conditions and hospital admissions	N = 835 hospital admissions
Bell *et al.* 2000 [36]	7 states: IL, IN, KY, OH, PA, VA, WV United States	1985-1990	Ecologic correlational study: relationship between cold environmental temperature and slip and fall-related injuries	N = 18 628 injuries

to have a high degree of completeness and quality since they are managed by public bodies. All studies adjusted for the most relevant confounder.

Without access to pre-registered protocol it was difficult to know whether or not there was reporting bias. However, we assigned a "probably low risk" for all studies because there was insufficient information to evaluate the risk of selective reporting but, being studies were exploratory in nature, they fully reported all multiple exposures-outcomes associations investigated.

We judged that there was high risk of outcome misclassification in six studies due to the lack of specificity of the outcome assessment in relation to heat-cold exposure or lack of validation of outcome data.

Four studies were considered having a high risk of exposure assessment bias due to the lack of validation of meteorological data and the use of average exposures for large geographic area.

Among other bias we considered the ecological bias in all studies except for Petitti 2013 [37] that was affected by inaccurate information on occupation status. Moreover all time-series studies had no information on population at risk in a specific time point leading to over or underestimation of relative risk.

Work-related injuries/illness and heat

All papers identified [21, 31-35, 37] assessing the effect of high temperature/heatwaves on workers' health showed an association with injuries in the workplace.

In a study from Quebec, Canada, Adam-Poupart *et al.* [32] observed a +0.2% increase in risk of daily work-related injury compensations per 1 °C increase in temperatures. Higher risk was observed for men, workers aged less than 45 years, various industrial sectors with both indoor and outdoor activities. Manual occupations were not systematically at higher risk than non-manual and mixed ones.

Fortune *et al.* [31] reported 273 emergency visits for heat illness from 2004 to 2010 with an increase of 75% in the rate of visits per degree Celsius above 22 °C. Emergency visits increased also with ozone exposure (+2%).

Similar findings was obtained by two Australian studies that used two different exposure indicators (temperature above a threshold and heatwaves) to examine how fluctuations in ambient temperature were associated with the number of daily injuries using data from compensation claims. Xiang[a] *et al.* [33] found that as temperatures rise, the number of daily injuries keep increasing but only up to a certain temperature, from which point on the number of injuries starts to decrease; probably due the fact that some work activities may be stopped in situations during extremely hot days where heat warnings are issued. The authors also identified that young people and males workers in industrial sectors were at higher risk. An increased risk was found in sectors that mostly work outdoors, such as agriculture,

Table 3a.
Exposure: high temperature. Characteristics of included studies and results*

Study	Heat exposure indicator	Outcomes	Main results**	Key for preventive measures
Adam-Poupart 2015 [32]	Daily maximum temperature (Tmax)	Work-related injuries	For all regions: IRR[a] = 1.002 (1.002-1.003) For an exposure at lag 3-day moving averages IRR = 1.003 (1.001-1.004) Men IRR = 1.003 (95% CI 1.002-1.005) *Age* 15-24 years = 1.008 (CI 1.005-1.010) 25-44 years = 1.003 (1.001-1.004) *Occupation* Outside IRR = 1.004 (1.001-1.006) Inside IRR = 1.003 (1.000-1.005)	None
Fortune 2014 [31]	Maximum temperature (Tmax) > 22 °C	Emergency department visits for heat illness using ICD-10-CA Codes T67:Effects of heat and light X30: Exposure to excessive natural heat W92: Exposure to excessive heat of man-made origin	Posterior median Relative rate[b] = 1.75 (1.56-1.99) Maximum air pollutant concentration Ozone Posterior median Relative rate[b] = 1.02 (1.00-1.04)	Occupational health risks are not limited to extreme temperatures when public health warnings are typically activated
Morabito 2014 [21]	Daily meteorological data of air temperature (T, °C), relative humidity (RH, %), wind speed (V, ms–1) and geopotential height (Hgt, m) Threshold ≥ 90°percentile (heat effect: 16,9 °C)	Outdoor Injuries	No significant result for all different geographical areas and mobility conditions *Workers who spend little time outdoors* Coastal area: % change in outdoor occupational injuries per 1 °C increase of air temperature = 8.2 (2.5-13.9)	None
Xiang 2014a [33]	Daily maximum temperature (Tmax) Heatwave ≥ 3 consecutive days with Tmax ≥ 35 °C	Work-related injury and illnesses (traumatic injuries, wounds, lacerations, and amputations, and musculoskeletal and connective tissue diseases)	*Gender* Women: IRR[c] = 0.935 (0.897-0.974) *Occupation* Laborers' and related workers' IRR = 1.054 (1.023-1.086) Tradespersons IRR = 1.056 (1.028-1.084) Intermediate clerical and service workers IRR=0.884 (0.831-0.941) Professionals IRR = 0.950 (0.912-1.028) *Industrial sector* Outdoor: IRR = 1.062 (1.022-1.103) Agricolture: IRR = 1.447 (1.125-1.861) Men: IRR = 1.653 (1.198-2.281) Age >55: IRR = 1.673 (1.049-2.667) Construction: IRR = 1.012 (0.936-1.093) Electricity, gas, water: IRR = 1.297 (1.049-1.604) Men: IRR = 1.387 (1.165-1.652) >55: IRR = 1.763 (1.161-2.676) Heat stress: IRR = 1.763 (1.161-2.676) Wounds laceration: IRR = 1.005 (1.028-1.154) Burns: IRR = 1.161 (1.010-1.334)	Male laborers and tradespersons >55 years of age in agriculture, forestry and fishing and electricity, gas and water industries are susceptible workers

(Continues)

Table 3a. (Continued)

Study	Heat exposure indicator	Outcomes	Main results**	Key for preventive measures
Xiang 2014b [34]	Daily maximum temperature (Tmax) Thresholds = 37.7 °C	Work's Injuries	Total effect: IRR = 1.002 (1.001-1.004) Men: IRR = 1.004 (1.002-1.006) Age ≤24: IRR = 1.004 (1.000-1.007) Business size: IRR 1.007 (1.003-1.011) *Occupation* Outdoor industries: IRR=1.005 (1.001-1.009) Labourers: IRR = 1.005 (1.001-1.008) Tradespersons: IRR = 1.002 (1.000-1.004) Intermediate production and transport: IRR = 1.003 (1.001-1.006) Agriculture, fishing and forestry: IRR = 1.007 (1.001-1.013) Construction: IRR = 1.006 (1.002-1.011) Electricity, gas and water': IRR = 1.029 (1.002-1.058) when Tmax was above 37.2 °C	None
Petitti 2013 [37]	Heat-related cases (n = 444)	Heat-related mortality	*Constructions* Men: Age-adj OR = 2.32 (1.55-3.48) Non-Hispanic white Age-adj OR = 2.10 (1.26-3.50) *Agriculture* Men: Age-adj OR = 3.50 (1.94-6.32) Non-Hispanic white Age-adj OR = 3.16 (1.01-9.88) *Occupation unknown* Men: Age-adj OR = 10.17 (5.38-19.43) Women OR = 6.32 (1.48-27.08)	None

*Only statistically significant results are reported in the Table; **95% confidence interval; [a]IRR= incidence rate ratio per 1 °C increase in Tmax; [b]rate of emergency department encounters for occupational heat illness per degree Celsius above 22 °C in the region's average maximum temperature; [c]percent change in the number of daily work-related injury claims during heatwave periods compared with non-heatwave periods; RR = relative risk; OR = odds ratio; IRR = incidence rate ratio; Tmax = maximum temperature.

construction and transport. Exclusively injuries among workers in the electricity, gas and water industries increased during extremely high temperatures.

Similar results was obtained by Xiang[b] *et al.* [34] that investigated the impact of heatwaves (consecutive extreme heat exposure) on work-related illnesses in a temperate Australian city. He found that males, workers in agriculture, forestry and fishing and electricity, gas and water industries had a significant increase of risk of occupational injuries. However, in this study people over 55 years old were at higher risk and increased risk was found in construction workers.

Morabito *et al.* [35], in Tuscany region, Italy, found that the peak of work-related accidents occurs at high but not extreme temperature. The authors suggest a timing of heat effect, with stronger effect of high temperatures recorded earlier in the summer season. Considering all occupational injuries recorded by National Institute of Insurance for Occupational Illness and Injury in Tuscany, the authors found no association for workers who generally spend half or most of their time outdoors, such as construction, land and forestry workers. However, these latter outdoor workers showed significant linear associations of injuries with typical (far-from-extreme) temperatures (between 10th and 90th percentile of temperature). This finding is in agreement with the Australian study.

A case control study [37] conducted in Maricopa County, Arizona, showed an association of heat-associated death with construction/extraction and agriculture occupations in men with a high risk in older men (>65 years).

Work-related injuries/illness and cold

Three studies [21, 31, 36] estimated the associations between low temperature and heat-related injuries or illnesses in workers. Morabito *et al.* [21] found that, among 162 399 workers, those working in plain areas and using vehicles other than cars (two-wheeled vehicles and other types-of-vehicles) had a higher risk of increased occupational injuries when temperature is below -0.8 °C. The authors suggested that, in these cases, workers are relatively unaccustomed to cold, and near freezing temperature might represent a stress factor compared with workers in typically cooler hill/mountain areas. No increase of injuries associated with low temperature were observed in workers who usually spent about half or most of their time outdoors, such as construction, land and forestry workers.

All the above suggests to recommend the interruption of some outdoor activities, especially by non-acclimatized workers when cold warnings are issued, in order to avoid injuries. Construction, land an forestry workers probably are more careful under certain weather conditions and, by themselves, limit their outdoor activities when temperature anomalies occur.

Fortune [31] found a significant increase (+15%) in emergency department visits for cold-related illness for

Table 3b.
Exposure: low temperature. Characteristics of included studies and results*

Study	Cold exposure indicator	Outcomes measured	Main results**	Key for preventive measures
Fortune 2014 [31]	Minimum temperature (regional average)	Emergency department visits Using ICD 10 classification: T33 – Superficial frostbite; T34 – Frostbite with tissue necrosis; T35- Frostbite involving multiple body regions and unspecific frostbite; T68- Hypothermia; T69- Other effects of reduced temperature; X31-Exposure to excessive natural cold; W93-Exposure to excessive cold of man-made origin	<0 °C : Posterior median Relative rate[a] = 0.85 (0.80-0.91) >0 °C: Posterior median Relative rate[a] = 0.90 (0.81-1.00) Maximum wind speed: Posterior median Relative rate[a] = 1.06 (1.02-1.11)	Occupational health risks are not limited to extreme temperatures when public health warnings are typically activated
Morabito 2014 [21]	Daily meteorological data of air temperature (T, °C), relative humidity (RH, %), wind speed (V, ms−1) and geopotential height (Hgt, m) Threshold below the 10th centiles (cold effect: −0.8 °C)	Outdoor Injuries	*% change of Outdoor Injuries* Whole of Tuscany: (n = 162 399) = 2.3% (1.3%-3.3%)[§] Inland plain: (n = 100 837) = 3.1% (1.3%-4.9%)[§] Coastal plain: (n = 61 562) = 2.4% (0.8-4.0) *** *In vehicles* Whole of Tuscany: (n = 62 581) = 3.4% (2.0-4.8) [§] *Standing/walking outdoors* Whole of Tuscany: (n = 99 818) =1.6% (0.4-2.8)*** *Types-of-vehicles* Two-wheeled vehicles Whole of Tuscany: (n = 17,872) = 5.0%(2.1-7.9)[§] Other types-of-vehicles Whole of Tuscany: (n = 18,121) = 7.1% (4.4-9.8)[§] *Types-of-jobs* Workers who spend little time outdoors Whole of Tuscany (n = 30,167) = 3.8% (1.8-5.8)[§]	Need of develop a geographically differentiated operative outdoor temperature occupational health warning system
Bell 2000 [36]	Average daily temperatures from the major metropolitan weather stations for each state	Incidence of slip and falls-related injuries at <=0 °C >0±10 °C >10 °C 3 location categories: mostly enclosed, outdoor, enclosed/ outdoor	Enclosed/outdoor vs mostly enclosed RR = 0.62 (0.58-0.67) Outdoor injuries vs mostly enclosed RR = 0.79 (0.72-0.88) Mostly enclosed ≤ 0 °C *vs* >10 °C: RR = 1.73 (1.48-2.03) Enclosed/outdoor injuries >0-10 °C *vs* >10 °C: RR = 1.17 (1.05-1.30) Enclosed/outdoor injuries ≤ 0 °C vs >10 °C: RR = 1.55 (1.36-1.78) Outdoor injuries >0 -10 °C vs >10 °C: RR = 1.08 (0.89-1.32) Outdoor injuries ≤ 0 °C vs >10 °C: RR = 1.78 (1.40-2.29)	Any intervention methods geared toward reducing injury incidents facilitated by cold weather must also be directed toward workers who do not have full-time outside work

*Only statistically significant results are reported in the Table; **95% confidence interval; *** $p < 0.01$; [a]Posterior median Relative rate = rate of emergency department encounters for occupational heat illness per degree Celsius below 22 °C in the region's average maximum temperature; [§] $p < 0.001$; ICD 10 = International Classification of Disease; RR = relative risk.

each degree decrease in the minimum temperature. A significant effect of wind speed as also observed (+6%)

Bell *et al.* [36] in seven US states, reported that slips and falls were the second most numerous type of injury among above-ground mining workers, accounting for 25% of the total number of injuries. The authors reported that the proportional injury ratio of slips and falls increased significantly as the temperature decreased.

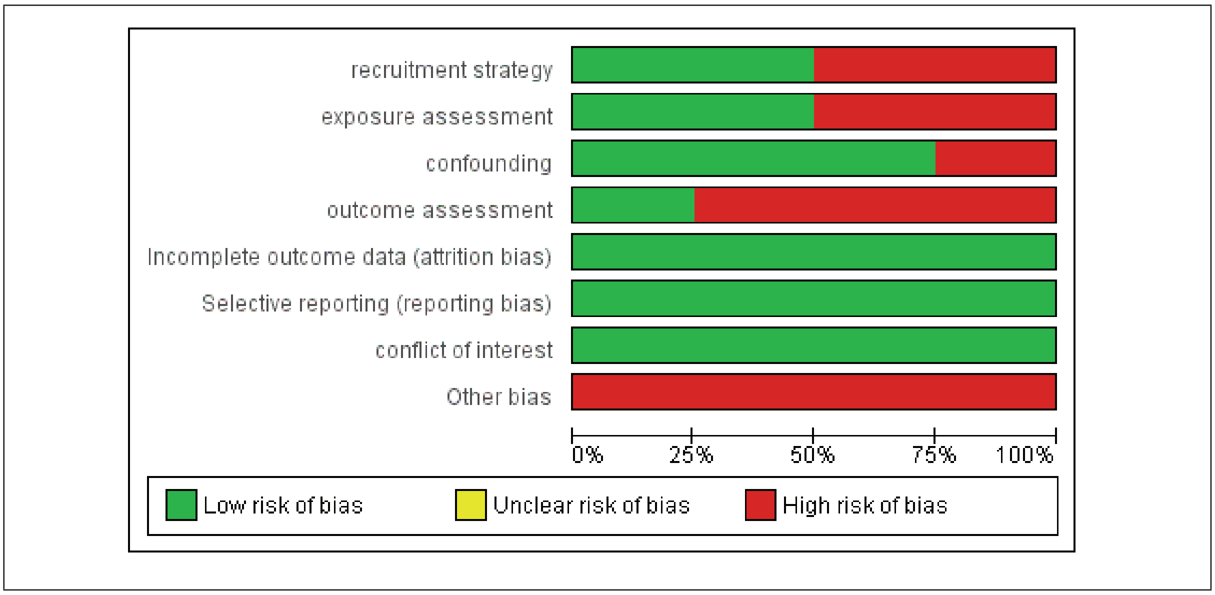

Figure 2
Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

This pattern also was evident in three work locations (enclosed, outdoors, enclosed/outdoor) when examined separately. Over all temperatures, slips and falls were a more important source of injury for the enclosed location than other locations.

DISCUSSION

Our work shows a relationship between extreme temperature (particularly for heat temperature) and work related injuries despite the few number of published studies.

We specifically identified studies in the following sectors: agriculture, fishing, construction, electrical and transport industries [21, 31-34, 37]. The most frequent kinds of injuries were slips, trips, falls, and wounds, lacerations and amputations [32-34].

The ecological study design and the lack of specificity of heat and cold related health effect on workers were the relevant sources of low quality in the studies involved in this systematic review. The risk of bias due to exposure misclassification is another concern for the included studies, due to the lack of validation and the limited geographic coverage of meteorological data. On the other hand even in the well conducted etiologic time-trend study the lack of information on daily variations of population at risk (*i.e.* workers) impairs the possibility to make any causal inference from the study results. This review underlines the need of cohort and case-control studies that overcome this limit and provide accurate estimate of relative risk of heat and cold effects on workers.

All selected studies underlined the complexity of relationship between heat temperature and occupational injury risk. The characteristics of job and procedure, the level of awareness, life habits and work organizations play a relevant role and a complete framework of studies regarding all these issues is still lacking. As showed in the recent review by Xiang and colleagues [38] the

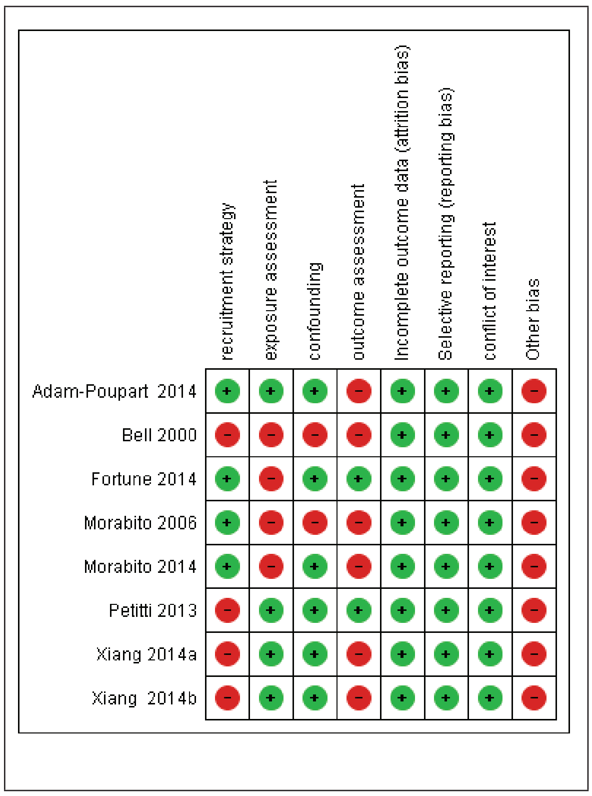

Figure 3
Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

prevention measures (including information and training about risk) are the basic tool to reduce work related injuries due to extreme temperature.

Recently the most important international Institute and Agency of public health have produced guidelines and recommendations about the risks of overheating for workers and gives practical guidance on how to avoid it [39, 40, 41]. All these documents underlined the role of prevention and in particular: i) to provide information about the risk for workers and employers; ii) to define programs for gradually adapting to extreme temperature; iii) to implement work organizations including turnover of workers exposed to heat temperature; iv) to avoid specific hard work in extreme weather conditions; v) to monitor the temperature and consider it in the program of job organization.

The most relevant occupational risk with extreme heat temperature is the dehydration with the consequence reduction of reactivity and quickness of reflexes. The use of cotton clothes and broad-brimmed heat and a correct use of breaks during working time are prevention measures with a simple implementation needing low resources and a good presumable effect in injuries risks reduction and control.

CONCLUSIONS

Despite the relationship between extreme temperature and population health has been well documented and several epidemiological studies have repeatedly demonstrated that hot weather (and hot waves particularly) contributes to excess morbidity and mortality, very few is known about the effect on work related injuries. Workers categories and job involved are not well documented and the extent of work injuries correlated to extreme ambient temperature at population level is not generally evaluated. The few available studies underlined the role of prevention and that it is important for policy makers and occupational health and safety authorities to receive scientific evidence regarding which categories of workers are at risk of injuries related to extreme temperature for adaptation purposes. The estimation of risk, the identification of specific jobs involved and the characterization of the complex mechanisms involved could help to define prevention measures particularly concerning work organization.

Author's contribution statement

Alessandro Marinaccio and Paola Michelozzi conceived the study. Michela Bonafede and Simona Vecchi defined its design, screened and selected studies, analyzed data and wrote the manuscript. Federica Asta and Patrizia Schifano participated to conceive the study, to define its design and to interpret data. All authors critically revised the manuscript and contributed for important intellectual contents.

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Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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