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## Nationwide epidemiological study for estimating the effect of extreme outdoor temperature on occupational injuries in Italy



Alessandro Marinaccio<sup>a,\*</sup>, Matteo Scortichini<sup>b</sup>, Claudio Gariazzo<sup>a</sup>, Antonio Leva<sup>a</sup>, Michela Bonafede<sup>a</sup>, Francesca K. de' Donato<sup>b</sup>, Massimo Stafoggia<sup>b</sup>, Giovanni Viegi<sup>c</sup>, Paola Michelozzi<sup>b</sup>, BEEP Collaborative Group (Ancona Carla, Angelini Paola, Argentini Stefania, Baldacci Sandra, Bisceglia Lucia, Bonomo Sergio, Bonvicini Laura, Broccoli Serena, Brusasca Giuseppe, Bucci Simone, Calori Giuseppe, Carlino Giuseppe, Cernigliaro Achille, Chieti Antonio, Fasola Salvatore, Finardi Sandro, Forastiere Francesco, Galassi Claudia, Giorgi Rossi Paolo, La Grutta Stefania, Licitra Gaetano, Maio Sara, Migliore Enrica, Moro Antonino, Nanni Alessandro, Ottone Marta, Pepe Nicola, Radice Paola, Ranzi Andrea, Renzi Matteo, Scondotto Salvatore, Silibello Camillo, Sozzi Roberto, Tinarelli Gianni, Uboldi Francesco)

<sup>a</sup> Occupational and Environmental Medicine, Epidemiology and Hygiene Department, Italian Workers' Compensation Authority (INAIL), Roma, Italy

<sup>b</sup> Department of Epidemiology, Lazio Regional Health Service, ASL Roma 1, Rome, Italy

<sup>c</sup> Italian National Research Council (CNR), Institute of Biomedical Research and Innovation (IRIB) (previously Institute of Biomedicine and Molecular Epidemiology "Alberto Monroy"), Palermo, Italy

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### ABSTRACT

**Background:** Despite the relevance for occupational safety policies, the health effects of temperature on occupational injuries have been scarcely investigated. A nationwide epidemiological study was carried out to estimate the risk of injuries for workers exposed to extreme temperature and identify economic sectors and jobs most at risk.

**Materials and methods:** The daily time series of work-related injuries in the industrial and services sector from the Italian national workers' compensation authority (INAIL) were collected for each of the 8090 Italian municipalities in the period 2006–2010. Daily air temperatures with a  $1 \times 1$  km resolution derived from satellite land surface temperature data using mixed regression models were included. Distributed lag non-linear models (DLNM) were used to estimate the association between daily mean air temperature and injuries at municipal level. A meta-analysis was then carried out to retrieve national estimates. The relative risk (RR) and attributable cases of work-related injuries for an increase in mean temperature above the 75th percentile (heat) and for a decrease below the 25th percentile (cold) were estimated. Effect modification by gender, age, firm size, economic sector and job type were also assessed.

**Results:** The study considered 2,277,432 occupational injuries occurred in Italy in the period 2006–2010. There were significant effects for both heat and cold temperatures. The overall relative risks (RR) of occupational injury for heat and cold were 1.17 (95% CI: 1.14–1.21) and 1.23 (95% CI: 1.17–1.30), respectively. The number of occupational injuries attributable to temperatures above and below the thresholds was estimated to be 5211 per year. A higher risk of injury on hot days was found among males and young (age 15–34) workers occupied in small-medium size firms, while the opposite was observed on cold days. Construction workers showed the highest risk of injuries on hot days while fishing, transport, electricity, gas and water distribution workers did it on cold days.

**Conclusions:** Prevention of the occupational exposure to extreme temperatures is a concern for occupational health and safety policies, and will become a critical issue in future years considering climate change.

\* Corresponding author at: Epidemiology Unit, Occupational and Environmental Medicine, Epidemiology and Hygiene Department, INAIL (Italian national workers compensation authority), Via Stefano Gradi 55, 00143 Rome, Italy.

E-mail address: [a.marinaccio@inail.it](mailto:a.marinaccio@inail.it) (A. Marinaccio).

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Epidemiological studies may help identify vulnerable jobs, activities and workers in order to define prevention plans and training to reduce occupational exposure to extreme temperature and the risk of work-related injuries.

## 1. Introduction

Due to climate change, heat waves have become more frequent and intense in recent decades [IPCC, 2015]. The Mediterranean region has been identified as a climatic hot-spot most vulnerable to climate change [Giorgi, 2006; Ciardini et al., 2016]. The temperature increase, measured in the coastal regions during the last decades, was found to be larger than at the global scale, with remarkable seasonal and geographical differences [Toreti et al., 2010]. The epidemiological association among high temperature, heat waves and population health effects has been largely analysed, using mortality and morbidity measures as health outcomes [Basu, 2009; Ye et al., 2012; Gasparri et al., 2015; Guo et al., 2017; Song et al., 2017]. There is undisputable evidence that hot weather contributes significantly to excess mortality, particularly among elderly and subjects with chronic diseases [Hales et al., 2014]. Cold temperature seems to affect mortality more indirectly, after longer exposure, during early extreme cold events and with significant variability for seasonality and climate conditions [Anderson and Bell, 2009; Díaz et al., 2019; Smith and Sheridan, 2019].

Despite the relevance for occupational safety policies, the health effects of extreme temperatures on occupational injuries have been scantily investigated. In the last decades, international institutions and public agencies have published documents promoting health programs and actions to improve working conditions and environments for all labour intensive jobs which are carried out in hot or cold indoor/outdoor conditions [CDC, 2008; NIOSH, 2016; UNDP, 2016]. They underlie that health effects of extreme temperature on workers are characterized by increasing perceived fatigue and decreasing reaction capacities. Work-related exposure to heat can result in reduced productivity and adverse health effects on workers, such as dehydration, spasms and growing risk of injuries that could be associated to sweaty palms, fogged-up safety glasses, and cognitive impairment (that is, mental confusion, impaired judgment, and poor coordination) [Dutta et al., 2015]. The relevance of loss in work capacity and productivity due to climate change has been repeatedly underlined and the associated costs have been estimated [Kjellstrom et al., 2016; Martínez-Solanas et al., 2018]. A recent survey carried out in Australia found that respondents were moderately concerned about workplace heat exposure, suggesting a need to strengthen workers' heat risk perception and refine current heat prevention strategies [Xiang et al., 2016]. For those jobs envisaging hot working conditions, such as smelters or metalworkers, heat waves represent an additional burden, which could lead to injuries [Xiang et al., 2016].

A systematic review of epidemiological studies [Bonafede et al., 2016a] on heat and cold temperature effects on work-related injuries identified categories of workers at risk and a meta-analysis of time-series and case-crossover studies have estimated a pooled risk between 1.002 and 1.014 (as mean value of pooled relative risks, according to different criteria of aggregation) [Binazzi et al., 2019]. Epidemiological studies appear to be limited in geographical extent, number of observations and exposure resolution. Two recent case-crossover studies have estimated that around 5% and 2.7% of occupational injuries in Adelaide (South Australia) and in Spain, respectively, were attributable to temperature [Martínez-Solanas et al., 2018; Varghese et al., 2019]. A study conducted in three major Italian cities: Milan, Turin and Rome, using occupational injuries collected by the Italian workers' compensation authority (INAIL), analysed the effects of temperature (high and cold). Results showed an effect of high temperature only among bricklayers, blacksmiths, mechanics, installers and asphalters, workers in the construction and energy sectors, and among outdoor workers or

workers performing both outdoor and indoor tasks. Conversely, only weak effects were observed for cold [Schifano et al., 2019].

Scientific evidence concerning the relative risk of work related injuries for extreme outdoor temperature and the identification of economic sectors and activities majorly involved are relevant for policy-makers and occupational health and safety practitioners to define guidelines and focused formation packages for prevention and adaptation of workplace extreme temperature exposure.

The ongoing project Big data in Environmental and occupational Epidemiology (BEEP) aims to collect and link environmental and health data from different sources to estimate the health effects and impacts in Italy (project details available at <https://www.progettobeep.it/index.php/en/>). The current study, carried out within the BEEP project, aims to estimate the risk of work-related injuries for extreme heat and cold outdoor temperatures, using worker's compensation claims in Italy from 2006 to 2010. Furthermore, effect modification by gender, age, firm size, economic sector and job type were also assessed.

## 2. Materials and methods

### 2.1. Workers' compensation claim data

This study considers occupational injuries ascertained in Italy in the period 2006–2010, with a claim protocol number by December 31, 2017. Data were extracted from the Italian national workers' compensation authority (INAIL) archives, which covers about 80% of the Italian workforce [INAIL, 2019; ISTAT, 2011]. INAIL receives claims for occupational injuries over the whole national territory, regarding all workers, except for some categories (armed forces, firefighters and police workers, air transport personnel, autonomous tradespeople and professionals with VAT registration), for which specific insurance systems have been established. A record-linkage procedure was performed using other INAIL archives to match each injury occurrence with information concerning the company/firm they worked for. We selected only injuries in industrial and services sector (excluding agriculture workers), according to the availability of firm size information only for these sectors. The label "agri-industry" in the analysed dataset has to be considered as the industrial transformation of agricultural products or refers to specific contractor workers. Data were anonymously treated through proper encrypting procedures in order to ensure privacy. Each subject was geographically assigned according to the municipality where injury occurred. The collected data includes demographic (gender, age at injury), occupational (economic sector of activity, type of job) and information on the gravity of the injury, measured as the duration of leave. Variables referring to the modalities of injury were not considered due to the large proportion of missing values. Causes of injury related to road accidents occurring during home-work-home travelling (e.g. commuting), students, and those not classified by INAIL as occupational accidents were excluded from the analyses.

### 2.2. Meteorological data

Italy is characterized by a cold humid subtropical or mild continental climate in the Northern regions and a Mediterranean climate with hot, dry summers and mild, wet winters in the central and southern regions. Daily air temperature with a  $1 \times 1$  km resolution derived using land surface temperature (LST) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on board the National Aeronautics and Space Administration (NASA) Terra satellite, air temperature ( $T_a$ ) from monitoring networks and spatio-temporal

land use data were utilized as temperature exposure. The methodology was developed elsewhere and details can be found in [deDonato et al. \[2016; Kloog et al., 2012; Kloog et al., 2014\]](#). Briefly, a 3-stage multivariate random effects model was developed in which, for stage 1, calibration between  $T_a$  measurements and LST data in pixels with both LST and  $T_a$  was defined for each year. For each day, random intercepts and slopes for LST were estimated to capture the day-to-day temporal variability of the  $T_a$ -LST relationship. The model was nested within climatic zones to account for the potential heterogeneity of the association across Italian climatic zones. The stage 2 model then predicted air temperature in grid cells without monitors but with available LST measurements. In the final stage, the model takes advantage of the association between grid cells LST values with  $T_a$  measurements located elsewhere, and of the association with available LST values in neighboring grid cells. Daily mean air temperatures at  $1 \times 1$  km spatial resolution for the study period (2006–2010) were obtained for the Italian domain. The model performance was excellent as the results of a cross validation procedure had an average  $R^2$  value of 0.97 and RMSPE of 1.4 °C across Italy. Average spatial and temporal correlations were 0.94 and 0.98, respectively, with RMSPE lower than 1 °C [[deDonato et al., 2016](#)]. The  $1 \times 1$  km gridded data were then averaged to obtain a daily mean temperature exposure for each municipality in Italy. Mean daily temperature, derived as described above, was the only measure available at national level with such a high spatial resolution for a 10-year period: hence, it was considered as the exposure of interest. Furthermore, it has been shown that the predictive ability of different temperature indicators in epidemiological studies is comparable [[Barnett et al., 2010](#)]: thus, it can be considered here to estimate work-related injuries at municipal level. The effect of humidity on temperature exposure has not been considered, but, as discussed in recent studies, the strong correlation between different measures of temperature means that, on average, they have the same predictive ability on estimating mortality, and potentially also on injuries occurrence [[Barnett et al., 2010; Varghese et al., 2018, 2019](#)].

### 2.3. Statistical analysis

The relationship between air temperature and injuries was evaluated with a time-series approach: for each of the 8090 Italian municipalities, the daily count of injuries was retrieved together with the daily mean temperature. Since Italy is divided in 20 regions and 110 provinces, a specific over-dispersed Poisson generalized linear regression model was run for each province. A Distributed Lag Nonlinear Model (DLNM) approach was used to take into account both the potential non-linearity of the dose response curve and a delayed effect of the exposure on the outcome [[Gasparrini, 2014; Gasparrini and Leone, 2014](#)]. The relationship between temperature and injuries was modelled through a B-spline with one internal knot, placed at the 50th percentile of region specific temperature distributions, and the lag-response with a categorical variable (lag window 0–2). To control for long time trends and seasonality, a quadruple interaction among municipality, year, month and day of the week has been included in the models. This choice was driven by the theoretical equivalence of such an approach to the “time stratified” case crossover analysis with controls selected in the same municipality, year, month and day of the week in which the case was observed [[Lu and Zeger, 2007](#)]. Other variables fitted in the model were: “holidays” (a 4-levels variable with value “1” on isolated days; “2” on Christmas, Easter and New Year's Day; “3” on the days surrounding Christmas, Easter and New Year's Day; “0” elsewhere); population decreases during the summer (a 3-levels variable with value “2” for the 2-week period around the 15th of August; “1” from 16 July to 31 August with the exception of the aforementioned 2-week period; “0” elsewhere); influenza epidemics (a 2-levels variable with value “1” on days of influenza epidemics, defined at regional level according to the National Influenza Surveillance System; “0” elsewhere). Then, from the province-specific estimated

coefficients, an overall national dose-response curve was estimated, using a multivariate meta-analytical regression [[Gasparrini et al., 2012](#)]. Province estimates are reported in Supplemental Material (Table S1). The effect of high temperatures was defined as the Relative Risk (RR) of injury for temperature increases between the 75th and the 95th percentile (mild heat) and above the 95th percentile (extreme heat). The effect of low temperatures was defined as the risk of injury for a decline in mean temperature between the 25th and the 5th percentile (mild cold) and below the 5th percentile (extreme cold) of mean temperature. For the same temperature intervals, we also estimated the impact of temperatures in terms of the number of attributable cases, using a methodology previously described [[Gasparrini, 2014](#)]. For both effect and impact, 95% Confidence Intervals (CI) were estimated. Effect modification was evaluated by age-category (15–34, 35–60, 60+), gender, firm-size (defined as number of employees: 0–10, 10–50, 50–250, 250+), injury's severity (defined as duration of leave: 4–15 days, 15–30, 30–60, 60+), economic sector and job type. Only sectors and job types that had been previously associated with outdoor temperatures in a literature review conducted by the Authors were selected [[Bonafede et al., 2016a](#)].

The analyses were run using R software (version 3.5.2) with the packages *gsm*, *dlm* and *mvmeta*.

### 3. Results

In the period 2006–2010, 2,277,432 occupational injuries were reported in Italy and considered in the study. Characteristics of the dataset are provided in [Table 1](#). The numbers of injuries decreased steadily in the considered period for both men and women, as did the gender ratio (M/F), passing from 3.73 in 2006 to 2.95 in 2010. More than half of included injuries are related to workers aged 35–60 years (61% in men and 69% in women). The duration of leave, considered as a proxy of injury severity, was on average < 15 days, without significant gender differences. The majority of injuries (37.9%) occurred in small firms (< 10 employees) according to the industrial Italian context which is characterized by the prevalence of small and medium enterprises.

The geographical distribution of mean daily temperatures for the 5th, 25th, 75th and 95th percentile for each of the municipalities in Italy are shown in [Fig. 1](#). A clear north-south gradient can be seen for heat and cold, with warmer temperatures in the south and colder values in the north. Furthermore, altitude and mountain ranges also create a clear thermal trend with lower percentile values in the Alps in the north and along the Apennines in central areas. At municipal level, the 25th percentile ranges from  $-8.8$  °C to  $13.0$  °C, while the 75th percentile ranges from  $2.9$  °C to  $23.4$  °C. Temperature extremes (5th and 95th percentile of mean temperature) range between  $-16.1$  °C and  $9.4$  °C and between  $8.2$  °C and  $28.7$  °C respectively. The relationship between mean daily temperature and work-related injuries is represented by the U-shaped curve in [Fig. 2](#). The curve for Italy is the estimated pooled curve obtained by the meta-regression model, as described in the Methods section. A significant risk of work-related injury can be observed, for heat and cold, as temperatures increase or decrease with different risk gradients as shown by the slope of the curve. The lowest point of exposure-response estimated curve has been identified at 25th percentile of temperature range.

The overall relative risks (RR) of occupational injury for different temperature ranges are shown in [Table 2](#). For mild heat (temperature between 75th and 95th percentile) the RR was equal to 1.07 (95% CI: 1.06–1.08) and 1.09 (95% CI: 1.07–1.12) for extreme heat (higher than 95th percentile). For mild (25th -to 5th percentile) and extreme cold (lower than 5th percentile) the RR were estimated equal to 1.03 (95% CI: 1.02–1.04) and 1.20 (95% CI: 1.15–1.26), respectively. Province level estimates for heat and cold are reported in Supplementary material Table S1. A heterogeneous effect of both heat and cold can be observed across Italy. The lag structure indicates an increase in injury risk

**Table 1**

Descriptive statistics of occupational injuries in Italy for the period 2006–2010 included in the Italian national workers compensation authority (INAIL) archive. Number of cases by gender, year, age at injury, economic sector of activity, job category, firm size and duration of leave.

Variable	Modality	Men		Women	
		Observed	%	Observed	%
Year of injury	2006	396,325	22.57	106,258	20.38
	2007	385,926	21.98	106,321	20.39
	2008	361,867	20.61	105,096	20.16
	2009	310,277	17.67	101,536	19.48
	2010	301,707	17.18	102,119	19.59
Age at injury	15–34	636,435	36.24	154,119	29.56
	35–60	1,071,466	61.01	357,459	68.57
	> 60	48,201	2.74	9752	1.87
Duration of leave	< 15	836,520	47.64	248,173	47.60
	15–29	371,328	21.15	112,295	21.54
	30–60	273,146	15.55	80,300	15.40
	> 60	231,981	13.21	60,183	11.54
	Not available	43,127	2.46	20,379	3.91
Firm size (n° of employees)	< 10	732,622	41.72	129,714	24.88
	10–49	404,585	23.04	82,877	15.90
	50–250	261,047	14.87	78,745	15.10
	> 250	357,848	20.38	229,994	44.12
Economic sector of activity (selected)	Agri-industry	14,715	0.84	6185	1.19
	Fishing	1450	0.08	83	0.02
	Mining	5867	0.33	124	0.02
	Oil extraction	1236	0.07	33	0.01
	Electricity, gas, water	13,762	0.78	1770	0.34
	Construction	370,409	21.09	3888	0.75
	Transportation	210,199	11.97	41,735	8.01
Job types (selected)	Other	1,138,464	64.83	467,512	89.68
	Asphalter	2158	0.12	6	0.00
	Roadman	2937	0.17	76	0.01
	Electrical mechanic	4292	0.24	150	0.03
	Blacksmith	13,773	0.78	95	0.02
	Servant	12,534	0.71	27,340	5.24
	Installer	9623	0.55	79	0.02
	Warehouse worker	67,554	3.85	7026	1.35
	Operator	3571	0.20	87	0.02
	Mechanic	117,841	6.71	3885	0.75
	Other	1,521,819	86.66	482,586	92.57
Overall		1,756,102	77.11	521,330	22.89

associated with cold temperature on the same days (lag 0), whereas the association with the high temperature remains significant for the following two days (Fig. 3). The attributable number of temperature-linked work-related injuries was 26,054 (5976 for cold and 20,078 for heat, respectively) in the considered period, corresponding to an average of 5211 injuries per year. A total attributable fraction to temperature of 1.14% has been estimated (0.06%, 0.17%, 0.63% and 0.14% due to extremely cold, mild cold, mild heat and extremely heat temperature, respectively).

The RRs of occupational injuries by gender, age, duration of leave, firm size, economic sector and job types for heat (above the 75th percentile) and cold (below the 25th percentile) are reported in Table 3. For heat, a higher risk of injury was estimated among males (RR 1.20, 95% CI: 1.16–1.25), younger workers (RR 1.25, 95% CI: 1.19–1.30 and RR 1.14, 95% CI: 1.10–1.18, for 15–34 and 35–60 years, respectively), and workers employed in small-medium size firms (RR 1.20, 95% CI: 1.15–1.25, RR 1.19, 95% CI: 1.11–1.27 and RR 1.20, 95% CI: 1.10–1.31, for firms with 0–9, 10–49, 50–250 employees, respectively). The opposite was observed for cold, with a larger risk of injuries among women (RR 1.51, 95% CI: 1.35–1.69), older workers (RR 1.80, 95% CI: 1.29–2.50 in the workers older than 60 years) and in workers employed in larger size firms (RR 1.47, 95% CI: 1.27–1.70 for firms with > 250 employees). Construction is the economic sector at higher risk of

injuries for exposures to heat (RR 1.30, 95% CI: 1.22–1.38); conversely, transport, fishing, electricity, gas and water and agriculture had a significant risk of injury for cold (RR 1.97, 95% CI: 1.42–2.73; RR 5.70, 95% CI: 2.80–11.58; RR 2.26, 95% CI: 1.15–4.46; RR 2.22, 95% CI: 1.24–3.97, respectively). When considering job types, installers, warehouse workers, operators and mechanics had significant risks of work-related injury when exposed to high temperatures (Table 3).

#### 4. Discussion

The national occupational injuries dataset and the use of high spatial resolution temperature data enabled us to estimate the risk of work-related injuries for exposure to both heat and cold at national level for the first time in Italy.

Considering future climate change, the analyses of temperature impact on occupational injuries risks and the definition of safety policies are crucial and the interest for this topic is increasing. Recently, a countrywide analysis for Spain has been published, including an evaluation of associated economic costs, quantified as 0.03% of the Spanish Gross Domestic Product, equal to 370 million euros per year [Martínez-Solanas et al., 2018]. An estimated attributable fraction of 4.85% of all claims for occupational injuries due to temperature has been reported for the area of Adelaide (South Australia) [Varghese et al., 2019], while the cited Spanish study found a fraction of 2.7% [Martínez-Solanas et al., 2018]. Our study found a lower incidence with an attributable fraction of 1.14%. The overall RRs were found consistent in general with the quoted recent studies, although the respective RRs values cannot directly be compared either for the different metric used or for the different reference of temperatures. A previous study conducted on three Italian cities found similar effect estimates [Schifano et al., 2019]. A recent meta-analysis summarized evidence on extreme temperature exposure and work related injuries [Binazzi et al., 2019]. Furthermore, a positive relationship was found when considering three case-cross-over studies [Spector et al., 2016; McInnes et al., 2017; Sheng et al., 2018] and five time-series studies [Xiang et al., 2014; Adam-Poupart et al., 2015; Garzon-Villalba et al., 2016; Martínez-Solanas et al., 2018; Riccò, 2018]. Nevertheless, the limited number of available epidemiological studies and the differences in population size, temperature exposure assessment, work-related injuries reckoning and the different statistical approaches suggest caution in the interpretation of the reported findings.

Our study found a positive association between occupational exposure to outdoor temperatures and work-related injuries, with a significant effect of heat and cold, for both moderate and extreme temperatures. The use of high spatial resolution (1 × 1 km) temperature data allows a better spatio-temporal characterization of worker exposure to outdoor temperature, thus obtaining more accurate effect estimates. In addition, the availability of a long time series of injuries data at national level, enabled us to study workers' vulnerability induced by job type, but also to evaluate geographical differences in effect estimates. The findings suggest a different pattern of risk associated with outdoor temperatures for heat and cold. Young male workers seem to be more vulnerable to occupational injury when exposed to heat, whereas, women and old age workers seem to be more susceptible to an occupational injury when exposed to low temperatures. These results are fully consistent with those also found in Spain [Martínez-Solanas et al., 2018] and with those obtained in Australia for the age at injury [Varghese et al., 2019]. As previously observed, the limited working experience and insufficient training could represent concurrent risk factors for young workers [McInnes et al., 2017]. The inadequate awareness of hazard, particularly for young male workers during hot days, seems to be the most reasonable explanation. This is remarkable from a risk prevention point of view, according to the opportunity of defining training and labour organizational measures for risk reduction.

Our findings provide an insight on the role of firm size in occupational injury due to outdoor extreme temperatures for the first time in

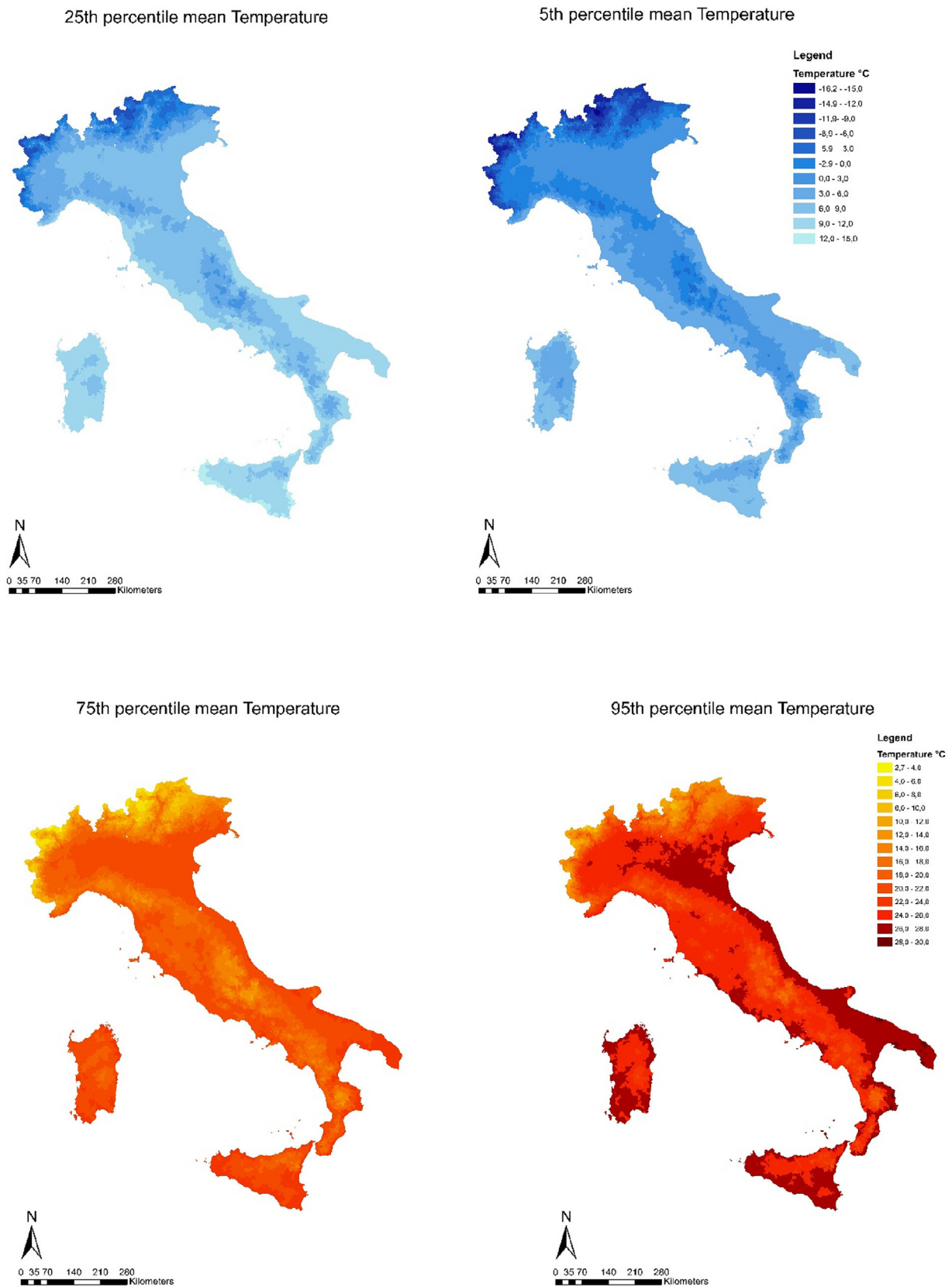


Fig. 1. Maps of 5th, 25th, 75th and 95th mean daily temperatures for each municipality in Italy during years 2006–2010.

Europe. The risk of injury linked to heat and cold is very different. Workers in large firms (> 250 employees) present a lower risk of injury for heat compared to workers employed in smaller firms. This finding

somewhat contrasts results from an Australian study which estimates a higher risk [Varghese et al., 2019]. Conversely, for cold, the risk of injury was the highest in large firms. It has been repeatedly

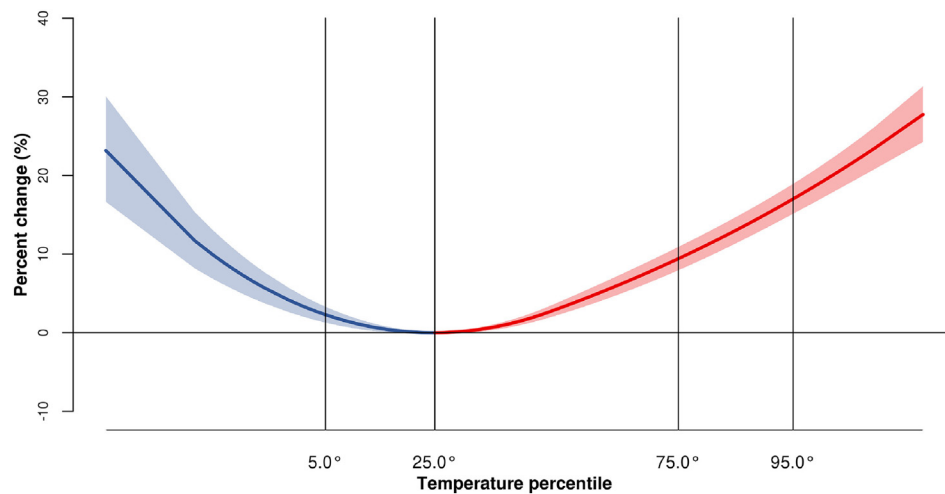


Fig. 2. Dose-response relationship. Percent change in work related injuries by temperature percentile. Blue and red areas correspond to cold and hot temperature effects. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

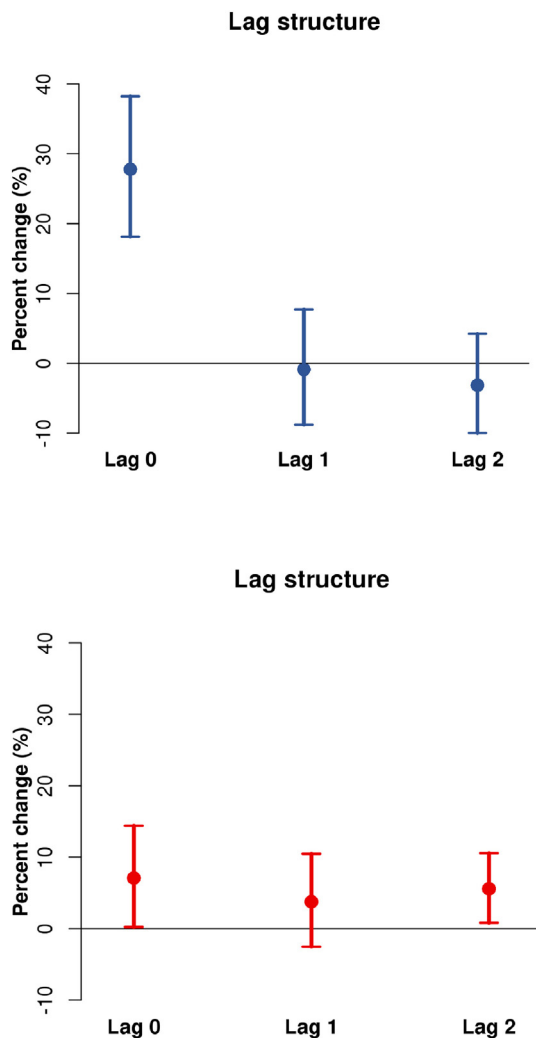


Fig. 3. Lag specific effects for the overall cumulative exposure-response relationship between outdoor temperature and occupational injuries for cold effects (a) and heat effects (b). Italy, 2006–2010.

demonstrated that workers in small enterprises have higher frequency of work accidents [Fabiano et al., 2004] and a poorer level of security performance [Sørensen et al., 2007]. Furthermore, employers in small

Table 2

Relative Risks (RRs, 95% CI) in work related injuries and attributable number of injuries for heat and cold, by temperature percentile ranges.

	RR (95%CI)	Attributable number of injuries (95%CI)
Cold (< 25° percentile)	1.23 (1.17–1.30)	5976 (779–11,040)
Extreme cold (< 5° percentile)	1.20 (1.15–1.26)	1600 (501–2641)
Mild cold (5°–25° percentile)	1.03 (1.02–1.04)	4376 (278–8399)
Heat (> 75° percentile)	1.17 (1.14–1.21)	20,078 (13,042–26,924)
Extreme heat (> 95° percentile)	1.09 (1.07–1.12)	3725 (2012–5393)
Mild heat (75°–95° percentile)	1.07 (1.06–1.08)	16,353 (11,030–21,531)

firms resulted less confident of the usefulness of occupational prevention measures [Bonafede et al., 2016b]. Niskanen and colleagues have discussed the lower capacity to invest in health promotion, and limited monitoring injuries and absence from work in small enterprises [Niskanen et al., 2012]. Our findings appear coherent with the evidence on work related injury for heat exposure, whereas the increased risk in large size firms for exposure to cold could be related to the absence of adequate prevention and hazard awareness of both workers and employers: therefore, further investigation is need. This study also identified specific job types at higher risk, particularly for heat. However, these results should be taken with caution, as the information was quite generic in the INAIL archives and possible misclassification might exist.

Our results show a non-linear relationship between outdoor temperature and work-related injury in Italy, showing an association for both cold and heat, as previously shown in other Mediterranean areas [Morabito et al., 2014; Martínez-Solanas et al., 2018; Riccò, 2018]. The effect of cold is immediate (lag 0), while the effect of heat is observed up to 2 days after exposure: both are consistent with the results obtained in Spain [Martínez-Solanas et al., 2018]. The increased risk of injury in the transport sector without temporal delay during cold days could be interpreted in the light of the correlation between extreme cold weather and dangerous roads status [Bergel-Hayat et al., 2013; Malyshkina et al., 2008].

This study has also several limitations. The agriculture sector has not been included in the analyses, although the relevance of the risk of

**Table 3**

Relative Risks (RRs, 95% CI) of work related injuries for heat and cold by gender, age at injuries, duration of leave, economic sector of activity, job category and firm size.

Variable	Modality	Observed	Cold effects (< 25 <sup>o</sup> percentile)	Heat effects (> 75 <sup>o</sup> percentile)
		n	RR (95%CI)	RR (95%CI)
Gender	Men	1,756,102	1.16 (1.09–1.23)	1.20 (1.16–1.25)
	Women	521,330	1.51 (1.35–1.69)	1.08 (1.02–1.14)
Age at injury (years)	15–34	636,435	0.98 (0.89–1.07)	1.25 (1.19–1.30)
	35–60	1,071,466	1.35 (1.25–1.46)	1.14 (1.10–1.80)
	> 60	48,201	1.80 (1.29–2.50)	0.91 (0.78–1.08)
Duration of leave (days)	< 15	836,520	1.02 (0.94–1.11)	1.22 (1.18–1.27)
	15–29	371,328	1.43 (1.27–1.61)	1.13 (1.07–1.19)
	30–60	273,146	1.36 (1.21–1.53)	1.14 (1.07–1.21)
	> 60	231,981	1.54 (1.32–1.80)	1.07 (0.99–1.16)
Firm size (n° of employees)	< 10	732,622	1.11 (1.02–1.21)	1.20 (1.15–1.25)
	10–49	404,585	1.24 (1.09–1.42)	1.19 (1.11–1.27)
	50–250	261,047	1.22 (1.03–1.46)	1.20 (1.10–1.31)
	> 250	357,848	1.47 (1.27–1.70)	1.06 (1.00–1.18)
Economic sector of activity (selected)	Agri-industry	14,715	2.22 (1.24–3.97)	1.14 (0.88–1.46)
	Fishing	1450	5.70 (2.80–11.58)	0.66 (0.18–2.36)
	Mining	5867	2.29 (0.74–7.10)	0.84 (0.46–1.53)
	Oil extraction	1236	3.42 (0.48–24.32)	0.78 (0.34–1.78)
	Electricity, gas, water	13,762	2.26 (1.15–4.46)	1.18 (0.80–1.73)
	Construction	370,409	0.81 (0.64–1.02)	1.30 (1.22–1.38)
	Transportation	210,199	1.97 (1.42–2.73)	1.11 (0.96–1.30)
	Asphalter	2158	0.67 (0.18–2.50)	1.03 (0.42–2.52)
	Roadman	2937	1.05 (0.36–3.07)	2.10 (0.91–4.84)
	Electrical mechanic	4292	1.30 (0.43–3.92)	1.95 (0.98–3.88)
Job types (selected)	Blacksmith	13,773	0.75 (0.35–1.57)	1.01 (0.60–1.69)
	Servant	12,534	1.69 (0.96–2.98)	1.09 (0.84–1.40)
	Installer	9623	0.66 (0.21–2.11)	1.73 (0.95–3.17)
	Warehouse worker	67,554	0.95 (0.57–1.61)	1.46 (1.13–1.90)
	Operator	3571	1.67 (0.45–6.12)	1.76 (1.16–2.65)
	Mechanic	117,841	1.05 (0.75–1.49)	1.33 (1.14–1.56)

occupational injury for agriculture workers in hot season was observed for both men and women [Martínez-Solanas et al., 2018]. Non-registered seasonal agricultural workers, mainly working immigrants, could not be considered in this study, as no compensation claims were produced. Recently, the role of socio-cultural conditions in the risk of occupational injuries, and stress perception for migrant workers during heat waves, has been shown and discussed [Riccò et al., 2019; Messeri et al., 2019]. A future prospective of our research is to carry out a specific analysis of injuries in agriculture using the high resolution temperature data for all Italian rural areas. The same applies to workers covered by insurance agencies other than INAIL, but this is a smaller proportion and restricted to some specific sectors. Nevertheless, nationwide compensation work-related injury claims provide a reliable source of data on occupational health.

The present study considers only outdoor exposure without taking into account indoor effects, or the combined effect, which could provide additional insights on subgroups of workers most at risk for exposures to extreme temperatures. Furthermore, there might still be some exposure error as we are considering a mean exposure value for all subjects and not individual exposures. Such information was clearly not available and, considering the sample size, it would have been a demanding task. Exposure assessment by the means of personalised temperature and physiological indicators measurement has been indicated as the remarkable direction for future research [Kuras et al., 2017].

Although biological mechanisms explaining the association between extreme temperature exposure and occupational injuries are complex, it appears ascertained that thermal discomfort can resolve in carelessness, fatigue, lack of alertness, loss of concentration, disorientation and reduced vigilance and it is not disputable that these conditions during working activities contribute to increase the risk of injury [Varghese et al., 2018]. The complexity of biological mechanisms contributed to make difficult to identify the role of extreme temperature in the injuries

risk at workplace: indeed, epidemiological methods to indirectly estimate the extent and the modalities of the association are required.”

In conclusion, our study provides valuable estimates on the risk of injuries among workers for exposures to heat and cold at national level, which can be used by policy makers and stakeholders to develop prevention measures and raise awareness to the risk related to current and future extreme weather events. The identified pattern of subgroup at high risk could help to guide regulators and governments for developing targeted injury prevention measures. Forecast scenarios of climate change suggest considering the prevention of occupational exposure to extreme outdoor temperature a priority in occupational safety and health field.

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