BMJ Open

Do exposure to outdoor temperatures and air pollutants affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023119
Article Type:	Research
Date Submitted by the Author:	11-May-2018
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Title Page

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Abstract

Objectives

Studies on the effect of temperature on rates of work-related injuries (WRI) have only recently emerged in the literature, and are constantly evolving in depth and scope. However, less is known about potential effects of air pollutants. Our objective was to analyze the association between WRI and specific air pollutants and air temperature in three major Italian cities, and to identify groups of workers more at risk in Italy.

Design time-stratified case-crossover study

Settings Milan, Turin and Rome, years 2001-2010

Participants A total of 468,816 WRI occurred between 2001-2010 in Milan, Turin and Rome and were extracted from the Italian national workers' compensation authority (INAIL) database.

Main outcomes Associations between WRI and temperature, particulate matter ≤ 10 µm (PM_{10}), nitrogen dioxide (NO_2), separately in the warm and in the cold season (WS, May-September; CS, November-February). Effect modification was studied by economic sector, occupational activity and indoor/outdoor place of work.

Results

Exposure to NO_2 (lag 0-8) showed the highest effect on the risk of WRI,with ORs ranging from 1.20 (*95% CI: 1.16-1.24*) in Milan to 1.30 (*95% CI: 1.24-1.37*) in Turin in the WS. The effect of exposure to PM_{10} was milder. Temperature was associated with risk of WRI only among those

working in construction (highest association in Rome *1.06*; *95% CI: 1.01-1.12)*, transportation (highest association in Milan 1.05; *95% CI: 0.96-1.14)* and the energy industry (highest association in Milan 1.57; *95% CI: 1.03-2.38)* in the WS in all cities. A weak effect of low temperatures was observed in the CS only in Rome.

Conclusions

Exposures to NO_2 resulted as strongest hazard for work related injuries, mainly in warm months, while the independent effect of temperature was significant only in specific subgroups of workers. These results introduce new evidence that if confirmed by other studies should be considered when planning health and safety prevention programs.

Keywords: air pollution; temperature; climate change; occupational health; work-related injuries; case crossover study

Strenghts and Limitations

- We used a very large dataset that was not derived from self-reported data
- We analysed data from three major Italian cities with different meteorological and pollution condition
- we estimated the independent effects of temperature and air pollution, controlling one for the other in the model
- daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL
- All exposure measures used were daily averages deriving from fixed points of measurement in the city

Background

Extreme weather events are becoming more frequent and intense as a result of climate change [1] and the relationship between extreme temperature and population health has been well documented.[2] Furthermore, air quality is influenced by a changing climate, which in turn impacts population health.[3]The association between outdoor temperature and air pollutants with mortality and morbidity in the general population has stimulated a large body of research, identifying susceptible subgroups, such as the elderly, people with chronic respiratory and cardiovascular diseases, and children.[4,5]

However, the consequences of climate and pollutants on work environments and their subsequent effects on job performance and safety are only recently coming to light.

Numerous factors such as worksite location and weather conditions may affect occupational exposure to air pollution; and likewise, indoor workplace environments may affect and exacerbate the adverse health effects of exposure to outdoor air pollutants. This is particularly a concern in workers with pre-existing health conditions and could theoretically lead to an increase in safety issues. The association between intense and prolonged occupational exposure to heat and and health effects on workers is characterized by dehydration and spasms, increased perceived fatigue, reduced productivity and decreased reaction capacities,[6] exacerbating hazards resulting from sweaty palms, fogged-up safety glasses, dizziness, and reduced brain function. [7-11] Young, male workers and those in occupations requiring physical labor, and outdoor workers, are at higher risk of adverse impact because of their exposure to heat and humid conditions.[12-14] As well, workers exposed to extreme cold may be at risk of cold stress, increased cardiovascular and respiratory diseases risks, musculoskeletal and dermatological disorders and injuries related to hypothermia.[7,15]

There is good evidence of the negative effects of short-term exposure to PM_{10} on respiratory health, such as aggravated asthma, respiratory symptoms and an increase in hospital admissions.[16] Nitrogen dioxide (NO_2) is a strong respiratory irritant gas originating from high-temperature combustion; a large study has shown a positive association between daily increases of NO_2 and natural, cardiovascular, and respiratory mortality.[17] Also, air pollution has been shown to negatively affect other outcomes such as productivity of agricultural workers.[18]

In addition, levels of exposure to pollutants might also vary according to several factors, such as SES, educational level, air conditioning use, proximity to roadways, and work environment.[19]

The warm season has been seen to be the strongest effect modifier of the effect of some pollutants on natural mortality;[20,21] this might be due to the fact that in summer, measured concentrations of air pollutants are more representative of true exposure because people spend more time outside and open windows more often.

A recently published review [22] summarized what is known about the heat and cold effects on work related injuries, and identified categories of workers at risk and evaluated heterogeneity and sources of bias of the included studies. Authors concluded that most studies had design limitations with regards to establishing a causal relationship and underlined the need for good quality studies that provide accurate estimates of relative risk of heat effects on occupational injuries.

The objective of this study is to estimate the short-term effects of summer and winter outdoor temperatures and air pollution on the risk of work related injuries, and to identify susceptible groups of workers.

Methods

Study population

We examined all work injuries that occurred between May and September and between November and February in the years 2001- 2010 in three major Italian cities: Milan, Turin and Rome.

Data were extracted from the Italian national workers' compensation authority (INAIL) database, which covers about 85% of Italian workers. For each injury episode that caused absences of three or more days, we gathered socio-demographic characteristics, occupation, and job title, and modalities and causes of the injury. Injuries in subjects younger than 17 years of age were excluded.

Meteorological and air pollution data

Rome, Milan and Turin are large metropolitan areas with different climatic conditions. Milan and Turin are located in Northern Italy and have a cold humid subtropical or mild continental climate, characterized by hot, humid summers with frequent thunderstorms and cold, damp winters often featuring fog in low-lying areas. Rome is located in central Italy 20 km from the Tyrrhenian Sea and has a typical Mediterranean climate with hot, dry summers and mild, wet winters.

Based on previous heat studies conducted in the same cities we chose maximum daily apparent temperature (MAT) [23,24] for the warm season (May-September), and maximum daily temperature (TMAX) for the cold season (November-February) as indicators of temperature.[25] These were measured at the airport station closest to each city. With regards to air pollutants, we used the 24-hr mean daily value of nitrogen dioxide (NO_2) and of particulate matter with an aerodynamic diameter of 10 μm (PM_{10}). Data were extracted from the Regional Environmental Protection Agency (ARPA); we used city-specific daily mean values for all subjects.[26]

Statistical analysis

The analysis was organized in three steps. Because not much is already known about the relationship between work related injuries and temperature and air pollution variations, we first explored the city and season-specific lag structures of each exposure. We used a non-linear distributed lag model (DLNM),[27] allowing a maximum lag structure of 30 days, with the aim of selecting the lags showing the strongest association.. As a second step we checked the linearity of the environmental exposure- injury risk relationship, at the lag defined by the previous step, through a Poisson generalized additive model, in each city and season, adjusting for long-time and seasonal trends.

As a third step the effect of environmental exposures on work-injury risk was evaluated using a time stratified case-crossover design separately for each city.[28] For each "case" (the day a work injury occurred) three more days were chosen as controls, matched by day of the week, month and year with the case day, to control for long-term trends, seasonality and day of the week. We

166 estimated odds ratios (OR) and 95% confidence intervals (CI) through a conditional logistic regression model, further adjusted for holidays and influenza epidemics (only in the cold season). Models were exposure, season, and city specific. Lags and shape of the relationship were those defined in the previous two steps.

We adjusted one exposure with the others in the model only when their correlation was lower than 0.4.

We tested potential effect modification of the environmental exposure-injury risk relationship by economic sector (using NACE classification), time spent outdoors or indoors and occupational activity, including interaction terms.

Patient and Public Involvement

Patients and or public were not involved in this study

Results

Study Population

We analyzed a total of 468,807 work-related injuries, more than half of which occurred in the warm season (Table 1).

Table 1. Injury distribution by workers' demographic and job characteristics, 2001-2010.

		Warm Season	Cold Season
Total : 468,807		262,804	206,003
Age group, n(%)			
	< 30	60,599 (23.1)	48,408 (23.5)
	30 - 50	158,086 (60.2)	121,997 (59.2)
	>50	44,119 (16.8)	35,598 (17.3)
Gender, n(%)			
	Male	165,054 (62.8)	124,671 (60.5)
	Female	97,750 (37.2)	81,332 (39.5)
Economic sector, n(%)			
	Transport	31,914 (12.1)	24,257 (11.8)
	Agro-industry	1,242 (0.5)	969 (0.5)

Fishery	2 (0.0)	2 (0.0)
Mineral extraction	179 (0.1)	140 (0.1)
Electricity gas and water	1,725 (0.7)	1,418 (0.7)
Construction	23,373 (8.9)	16,208 (7.9)
Food, textile and wood industry	6,588 (2.5)	5,264 (2.6)
Electrical, chemical, petrochemical and rubber processing industry	8,445 (3.2)	6,511 (3.2)
Mechanical and metallic industry	10,860 (4.1)	7,413 (3.6)
Business and food service	44,810 (17.1)	34,690 (16.8)
Healthcare system	14,719 (5.6)	11,980 (5.8)
Public services, financial activities	118,947 (45.3)	97,151 (47.2)
Working time spent, n(%)		
Indoor	105,215 (40.0)	87,578 (42.5)
Indoor high temperature exposure	7,099 (2.7)	5,669 (2.8)
Indoor/Outdoor	88,231 (33.6)	65,299 (31.7)
Outdoor	23,585 (9.0)	16,442 (8.0)
Missing	38,674 (14.7)	31,015 (15.1)

Meteorological and air pollutants data

Warm season

Rome and Milan showed a common median value of MAT of about 28°C, while Turin showed a median MAT of 26°C. Rome had the higher minimum temperature, (**eTable 1**, supplementary material). As for pollution, values were quite similar in the three cities; we observed a moderate correlation between PM_{10} and NO_2 ($\rho \geq 0.5$) in all cities and between MAT and PM_{10} ($\rho = 0.4$) in Rome (**eTable 2**, supplementary material).

Cold season

Rome was the warmest city with a median TMAX of 13°C, while Turin and Milan were cooler and had similar median TMAX values of about 8°C. We observed a minimum of -8°C for TMAX in Turin and of -3°C in Milan, while Rome never went below 5°C of TMAX (**eTable 1**, supplementary materials). As for air pollution we observed similar values of NO_2 in the three cities, and higher values of PM_{10} in Turin and Milan. (**eTable 1**, supplementary materials). We observed positive correlations between PM_{10} and NO_2 in Turin (ρ=0.5) and Milan (ρ=0.6) (**eTable 2**, supplementary material).

<u>*Lag structure and shape of the exposure-work injury relationship (step 1 and step2)*</u>

Analysis of the lag structure indicated a delayed effect on injury risk of all analysed exposures; during the warm period the greatest effects were observed within the first week after exposure, while in the cold period effects could persist up to 20 days. (**eFigure 1**, **eFigure 2**, **eFigure 3**, supplementary material). A summary, for all exposures, of chosen lags and of the shape of relationship (linear/non linear) with WRI risk were reported in Figure 1.

In the warm period the work-related injury/temperature relationship was linear in Rome (**eFigure 4**, supplementary materials) and non-linear in Turin and Milan. In these two cities we estimated ORs comparing city-specific MAT levels chosen in order to maximize the contrast. In particular, we compared the 90th percentile (33°C) versus the 50th (26°C) in Turin and 90th percentile (34°C) versus the 10th (21°C) in Milan; results for Rome were reported for the interquartile range (32°C versus 24°C) to facilitate comparisons. As for air pollutants, the PM_{10}/WRI relationship was linear in Rome and nonlinear in Turin and Milan (**eFigure 5**, supplementary material), while the NO_2/WRI relationship was linear in Rome and Turin and non-linear in Milan (**eFigure 6**, supplementary material).

In the cold months, the WRI/temperature relationship was non-linear in the three cities (**eFigure 4**, supplementary material). We estimated ORs comparing city-specific TMAX's levels, in particular we compared the 10th percentile (4°C) versus the first percentile (2°C) in Turin, the 25th percentile (6°C) versus the 5th (4°C) in Milan and the 25th percentile (10°C) versus the 5th (8°C) in Rome. Air pollutants–WRI relationship was linear in all the three cities for both PM_{10} and NO_2. We estimated effects comparing the 95th percentile versus the 25th in both climatic periods (**eFigure 5**, **eFigure 6**, supplementary material).

<u>*Conditional logistic regression models (step 3)*</u>

In the warm season, the univariate analysis showed a positive association between WRI and MAT, PM_{10} and NO_2 in all cities. In the cold season, we observed an inverse association between WRI and TMAX and a positive one between WRI and NO_2 in all cities, and between WRI and PM_{10} only in Rome.

When adjusting temperature for one pollutant at a time in the warm months, the association with WRI resulted to be non-significant, while there was a positive significant effect when adjusting for temperature of both PM_{10} and NO_2 in all cities; in the cold months we observed a significant association of NO_2 with WRI in all cities, and of TMAX and PM_{10} in Rome. We reported only adjusted estimates. (Table 2)

Table 2. Adjusted Odds ratios (ORs) of WRI for temperature and air pollutants levels variations in Turin, Milan and Rome. Period 2001-2010.

Environmental exposures	OR (95% CI)	Comparison (percentile)
WARM SEASON *(May-September)* [a]		
Turin		
Daily maximum apparent temperature (°C) (Lag[*] 1-7) [b]	1.02 (0.99, 1.06)	90th vs 50th
PM_{10} (μg/m^3) (Lag[*] 0-6) [c]	1.09 (1.05, 1.12)	95th vs 25th
NO_2 (μg/m^3) (Lag[*] 0-8) [c]	1.30 (1.24, 1.37)	95th vs 25th
Milan		
Daily maximum apparent temperature (°C) (Lag[*] 1-7) [b]	1.01 (0.98, 1.04)	90th vs 10th
PM_{10} (μg/m^3) (Lag[*] 0-7) [c]	1.13 (1.10, 1.16)	95th vs 25th
NO_2 (μg/m^3) (Lag[*] 0-8) [c]	1.20 (1.16, 1.24)	95th vs 25th
Rome		
Daily maximum apparent temperature (°C) (Lag[*] 1-7) [b]	1.00 (0.99, 1.02)	75th vs 25th
PM_{10} (μg/m^3) (Lag[*] 0-7) [c]	1.15 (1.11, 1.18)	95th vs 25th
NO_2 (μg/m^3) (Lag[*] 0-8) [c]	1.22 (1.16, 1.28)	95th vs 25th
COLD SEASON *(November – February)* [d]		
Turin		
Daily maximum temperature (°C) (Lag[*] 6-21) [b]	1.05 (0.93, 1.18)	1th vs 10th
PM_{10} (μg/m^3) (Lag[*] 2-12) [e]	0.98 (0.94, 1.02)	95th vs 25th
NO_2 (μg/m^3) (Lag[*] 0-4) [e]	1.11 (1.06, 1.17)	95° vs 25th
Milan		
Daily maximum temperature (°C) (Lag[*] 6-21) [b]	0.94 (0.92, 0.96)	5th vs 25th
PM_{10} (μg/m^3) (Lag[*] 0-3) [e]	1.00 (0.98, 1.03)	95th vs 25th
NO_2 (μg/m^3) (Lag[*] 0-3) [e]	1.09 (1.06, 1.11)	95th vs 25th

Rome		
Daily maximum temperature (°C) (Lag* 0-6) [b]	1.02 (1.00, 1.04)	5th vs 25th
PM_{10} (μg/m^3) (Lag* 5-19) [e]	1.05 (1.03, 1.08)	95th vs 25th
NO_2 (μg/m^3) (Lag* 1-4) [e]	1.04 (1.02, 1.06)	95th vs 25th

[a] Final conditional regression model adjusted by holidays.
[b] Adjusted for NO2
[c] Adjusted for MAT
[d] Final conditional regression model adjusted by influenza epidemics and holidays.
[e] Adjusted for TMAX
* Lags expressed in days.

<u>*The effect of NO_2*</u>

Exposure to NO_2 showed the highest positive association with the risk of being injured at work in both seasons and in all cities. In the warm season, an increase of NO_2 from the 25th to the 95th percentile was associated with an increase in work injuries ranging between 1.20 (95% CI: 1.16-1.24) in Milan and 1.30 (95% CI: 1.24-1.37) in Turin; in the cold season the effect of NO_2 was lower, ranging between 1.04 (95% CI: 1.02-1.06) in Rome and 1.11 (95% CI: 1.06-1.17) in Turin. (Table 2)

<u>*The effect of PM_{10}*</u>

An increase of PM_{10} from the 25th to the 95th percentile in the warm season was associated with an increase in WRI ranging between 1.09 (95% CI: 1.05-1.12), in Turin, and 1.15 (95% CI: 1.11-1.18), in Rome. During the cold season, we found a significant effect of PM_{10} only in Rome with a 1.05 (95% CI: 1.03-1.08) increase in WRI. (Table 2)

<u>*The effect of temperature*</u>

No significant association between temperature and injury risk was observed in the warm season overall, but for workers in the following economic sectors: transportation (Turin 1.00 - *95% CI: 0.89-1.13;* Milan 1.05; *95% CI: 0.96-1.14; Rome 1.04*; *95% CI: 1.00-1.09)*, construction (Turin 1.07 - *95% CI: 0.95-1.21;* Milan 1.07; *95% CI: 0.97-1.17; Rome 1.06*; *95% CI: 1.01-1.12)* and energy industries (Turin 1.56 - *95% CI: 0.95-2.58;* Milan 1.57; *95% CI: 1.03-2.38; Rome 1.00*; *95% CI: 0.85-1.18)* (Figure 2). However the effect was modest.

The association between WRI and temperature or air pollutants by occupational activity was estimated only for those injuries occurred in one of the three economic sectors with a significant association between temperature and WRI, and only in the warm season (Transportation, Construction, and Electricity Gas and Water - Figure 2). In order to have enough statistical power we aggregated into a single category all those occupational activities for which less than 20 injuries were reported in at least one city. Blacksmith, mechanic, installer, motor worker, road worker, warehouse worker, attendant and asphalter were the only activities for which we observed a significant effect of temperature on WRI. The highest effects were observed for road workers (*OR:4.05 - 95% CI:1.20-13.66),* warehouse workers (*OR:4.45 - 95% CI:1.10-18.02)* and attendants (*OR:6.91 - 95% CI:1.42-33.57)*. (Figure 3)

We also observed a significant effect of MAT on those working outdoors in Milan (OR:1.12 - *95% CI: 1.02-1.23)* and Rome (OR:1.07 - *95% CI: 1.01-1.12)*, and among those working both outdoors and indoors only in Rome (OR:1.03 - *95% CI: 1.00-1.06).* No effect was observed among those working only indoors (Figure 4).

In the cold season, a decrease of TMAX from 4°C to 2°C was associated with a weak and not significant increase in WRI (OR: 1.02; 95% CI: 1.00-1.04) in Rome (Table 2) while in Turin and Milan no effect was observed.

No effect modifiers of TMAX-WRI in the cold season or of the air-pollutant/WRI relationship in either season was found.

Discussion

This is the first study conducted in Italy to analyze the independent effects of temperature (hot and cold) and air pollutants on the risk of work-related injuries. The strongest effects on WRI risk was due to exposure to NO_2 in the warm season, with a WRI risk up to 1.3 times higher when NO_2 levels increased from the 25th to 95th percentile of its city-specific distribution.

In general we observed a significant association between exposure to NO_2 and WRI in both seasons, in all job categories, and in all cities; and between PM_{10} and WRI only in Rome during the warm season. Temperature showed a significant effect only in specific occupational activities during the warm season (April to October).

The relationship between NO_2 and the occurrence of work related injuries had a similar shape in the three cities in both periods (**eFigure 6**, supplementary material). As expected, NO_2 values were lower in the warm than in the cold season, with median values in the three cities of about 50 μg/m^3 and 73 μg/m^3 respectively. Despite this, there was a stronger association between NO_2 and WRI in the warm than in the cold season, possibly due to a "ceiling effect", given that levels of NO_2 in the cold season are always higher. It is also noticeable that the effect of NO_2 remained constant regardless of economic sector or occupational activity.

PM_{10} levels showed a similar trend as NO_2, with lower levels in the warmer months and higher levels and a low day by day variability in the cold period. Only in Rome, the southern of the three cities, PM_{10} showed lower and more variable levels in the cold period. (**eTable 1**, supplementary material); and it is interesting to observe that an increase of PM_{10} is associated to an increase in WRI in this season only in Rome. In the warm months the effect of PM_{10} is consistent in the three cities, but lower then that of NO2. On days in which PM_{10} levels reach the 75th percentile of the city specific distribution the risk of WRI is 10% higher than on days when PM_{10} levels are around their 25th percentile.

The similar shape of the pollutant-WRI risk both among cities and among pollutants supports our study's robustness Furthermore, what is known about the short term health effects of exposure to air pollutants [29-31] made it reasonable to think of potential effects on work-related injuries. Some previous studies have analyzed health-related outcomes in specific categories of workers, particularly those exposed to urban stressors, such as street vendors and policemen, and they showed some effects on cardiovascular diseases, pregnancy outcomes, and respiratory diseases.[32-36,18] One study measured a negative economic impact of exposure to air pollutants in agriculture workers, finding lower productivity on more polluted days.[18] (Zivin and Neidell, 2012). Finally, a recent study [32] tried to measure the association between occupational exposure to ozone and respiratory diseases, with no conclusive results.

Mounting experimental evidence suggests that, in addition to the cardiopulmonary system, the brain may be a target of air pollution. Specific mental and neurological disorders, such as depression and headache, as well as suicide have all been linked to ambient air pollution.[37,38] Inhaled concentrated ambient particulate matter may translocate to the brain and produce neuroendocrine and neuropathological alterations.[39] The lag of these effects was short, two or three days;[40] so it is reasonable to think that these exposures might explain the association between pollution and work related injuries.

As for heat, our study showed an increase of injuries only among bricklayers, blacksmiths, mechanics, installers and asphalters working in transportation, construction and energy economic sectors , and in the more generic group of those working outdoor or performing both outdoor and indoor tasks, but not among those who work only indoors. These results are consistent with previous studies.[41,42]

It is interesting that the unadjusted OR of MAT on WRI during the warm season ranged from 1.03 in Rome (75° vs 25° percentile, range=8°C) to 1.06 in Turin (90° vs 50° percentile, range=7°C), but these effects lowered to 1.01 and became not significant when adjusting for air pollution. The observed confounding of temperature by pollution should be considered when comparing our results to unadjusted estimates of temperature-WRI associations from other published studies.

Two previous studies conducted in Italy [43] and in Australia [41] found an inverse U-shaped relationship between high temperatures and WRI in summer, with maximum risk on warm days but not on extremely hot days. We observed a similar relationship in Turin and Milan, where maximum effects were observed at 33°C-34°C, while they remained stable or decreased afterwards. In Rome, which experiences warmer summer conditions than Milan and Turin, we found a linear relationship consistent with what was observed in two recent studies conducted in Melbourne and in Quebec.[42,12] Different population characteristics as well as temperature distributions might influence these differences between cities. Furthermore, it has to be considered that the trend in the effects observed in Milan and Turin might be biased by the lower statistical power in the highest extremes of the temperature distribution, due to the fewer days observed with those temperature levels. This is not the case in Rome where temperatures even above 34°C are adequately represented.

Ambient heat might increase metabolic heat that is normally produced in activities requiring physical exertion; accordingly we have observed an effect of heat in more physically demanding economic sectors and occupational activities. We categorized workers according to three different criteria as suggested in a previous study:[12] economic sector, occupational activity and outdoor or indoor location. This classification allowed us to measure both the risk associated with physical demands (economic sector and occupational activity) and the gradient of exposure to outdoor heat. Our results showed higher susceptibility among those working outdoors and no effects on those working only indoors, confirming that those working outdoors are more susceptible to pollution and temperatures exposure. However, when analysing single occupational activities, we found that among the most susceptible there were some (mechanics, warehouse workers and attendants) who spend more time indoor than outdoor but still require high physical exertion. Strenuous activity, and use of heavy impermeable personal protective clothing might increase metabolic heat and increase the risk of injuries. This might suggest that the level of physical strength required by the occupation might be an important effect modifier to be taken into account for heat-related risk, independent of work location.[12]

An important strength of this study is that we estimated the independent effects of temperature and air pollution, controlling one for the other in the model. Also, we used a very large dataset that was not derived from self-reported data. However, our study presents some limits. The study population was drawn from the Italian public insurance system database that covers all work-related injuries due to violent causes that leads to death, permanent disability or temporary total disability lasting at least three days, and all occupational diseases. It is remarkable to consider that workers covered by the public insurance system for injuries and occupational diseases make up approximately 80-85%

of the whole workforce in Italy. However, daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL. Some occupational activities, such as firefighters and the armed forces, benefit from a specific welfare system in Italy and are not included in the analyzed dataset. The distribution of daily injury claims by economic sector varies greatly and the relatively small numbers in some sectors dictates a cautious interpretation of results for less represented subgroups.

All exposure measures used were daily averages deriving from fixed points of measurement in the city, implying each worker was attributed the same level of exposure independently of his location in the city at the moment of injury, thus having a potential bias in exposure due to different temperatures and pollutants within the city on a given day. However, the error associated with this generalization in exposure is considered to be low.[44] Finally collinearity among NO_2 and PM_{10} didn't allow to adjust one pollutant for the other, so that the estimate of pollutant effect might be confounded by concomitant exposure to the other one. This limit is proper of almost all air pollution studies.

Conclusions

Our results suggest that exposure to nitrogen dioxide in the warm months strongly increase the risk of work related injuries among all categories of workers. These results suggest the need to further look into this association, to confirm our findings and to better understand the underlying mechanisms. Our results also show that , after removing the confounding effect of co-exposure to air pollution, the exposure to high temperature represents a risk only among workers who have heavier work loads and among those who spend most of their time outdoors. Finally our results confirms that in Italy, which is a Mediterranean country with a generally mild climate, ambient exposures represent a hazard for work related injuries only during the warmer months.

These results contribute to the increasing knowledge about the association between temperature and work related injuries, and add new evidence about the potential effects of pollutants that have not yet been studied in Italy except on very specific subgroups.

Identifying specific subgroups of workers as the most susceptible to these specific exposures is crucial information for public health organizations in order to properly target prevention plans.

Abbreviations

WRI, work related injuries;

PM_{10}, particulate matter with an aerodynamic diameter of 10 μm or less;

NO_2, nitrogen dioxide;

MAT, maximum apparent temperature;

TMAX, maximum temperature;

DLNM, non-linear distributed lag model;

OR, odd ratio;

CI, confidence interval.

Declarations

Acknowledgments

Authors aknowledge Dr. Simona Vecchi for her suggestions in the final revision of the manuscript; Giuseppe Campo and Fabio Cosimi (INAIL, Rome) for supporting in the retrieving and interpretation of injuries data and Julie Sawitzke for her carful editing and English review.

Funding

The study was carried out within "Cambiamenti climatici, inquinamento atmosferico e pollini: Modello integrato di monitoraggio dell'esposizione ambientale, allerta, sorveglianza rapida sanitaria e promozione di misure di prevenzione per ridurre l'impatto sulla salute"funded by CCM – Ministero della Salute.

Availability of data and materials

The data that support the findings of this study are available from *Occupational and Environmental Medicine, Epidemiology and Hygiene Department, Italian Workers' Compensation Authority (INAIL), Rome, Italy* but restrictions apply to the availability of these data, which were used within the collaboration for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request. and with permission of INAIL.

Authors' contributions

PS conceptualized and designed the study, drafted the manuscript. FA carried out the statistical analyses, reviewed and revised the manuscript. AM and MB contributed to the draft, critically reviewed the manuscript. MD critically reviewed the manuscript. PM collaborated to conceptualize and to desig the study, reviewed and revised the manuscript. All authors read and approved the final manuscript as submitted.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests to disclose.

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Figures:

Figure 1. Graphical summary of lags and shapes of exposures/WRI relationship (linear/non linear) by season and city.

Figure 2. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase*, by economic sectors, during warm season (May-September) in Turin, Milan and Rome.

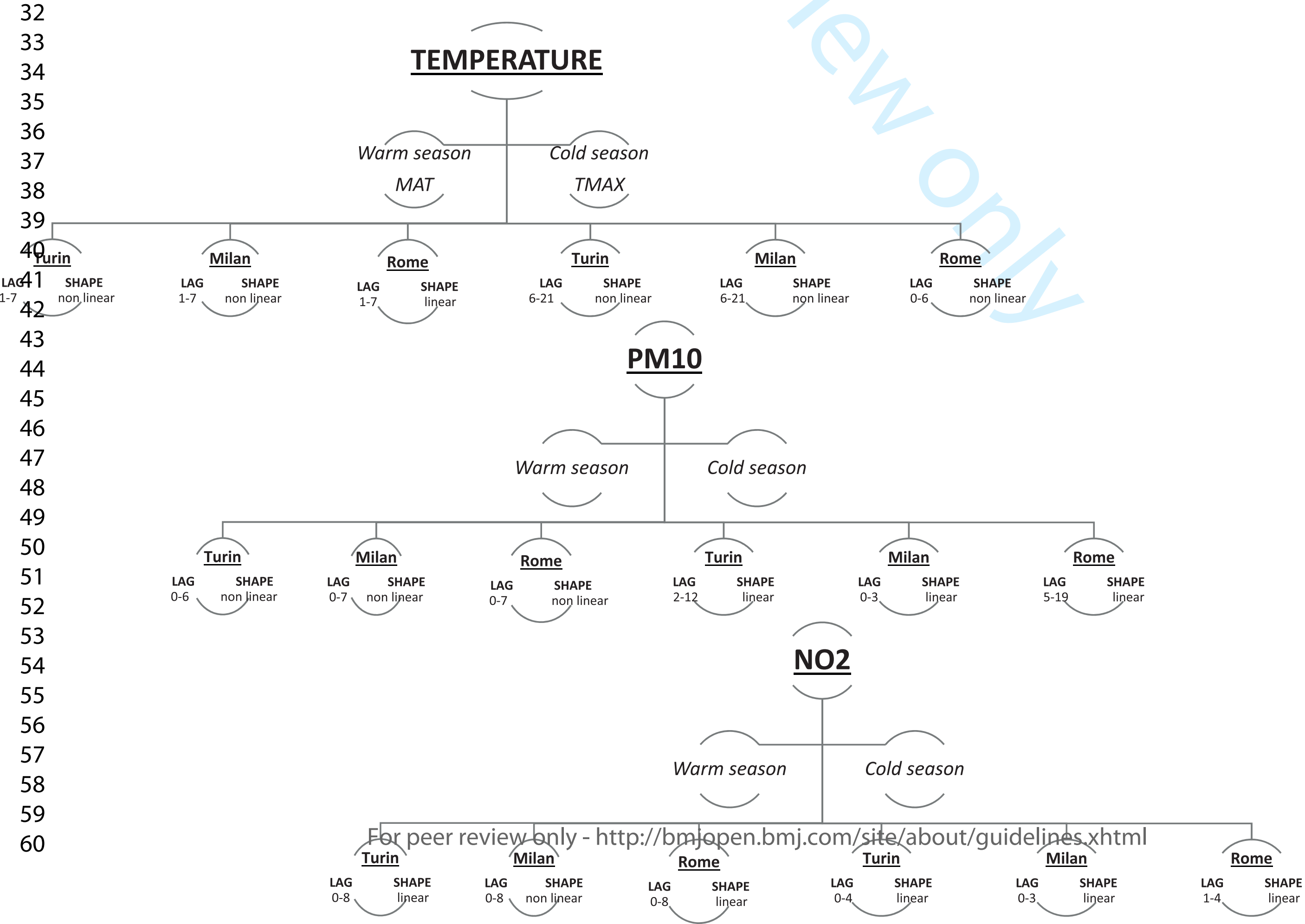
* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

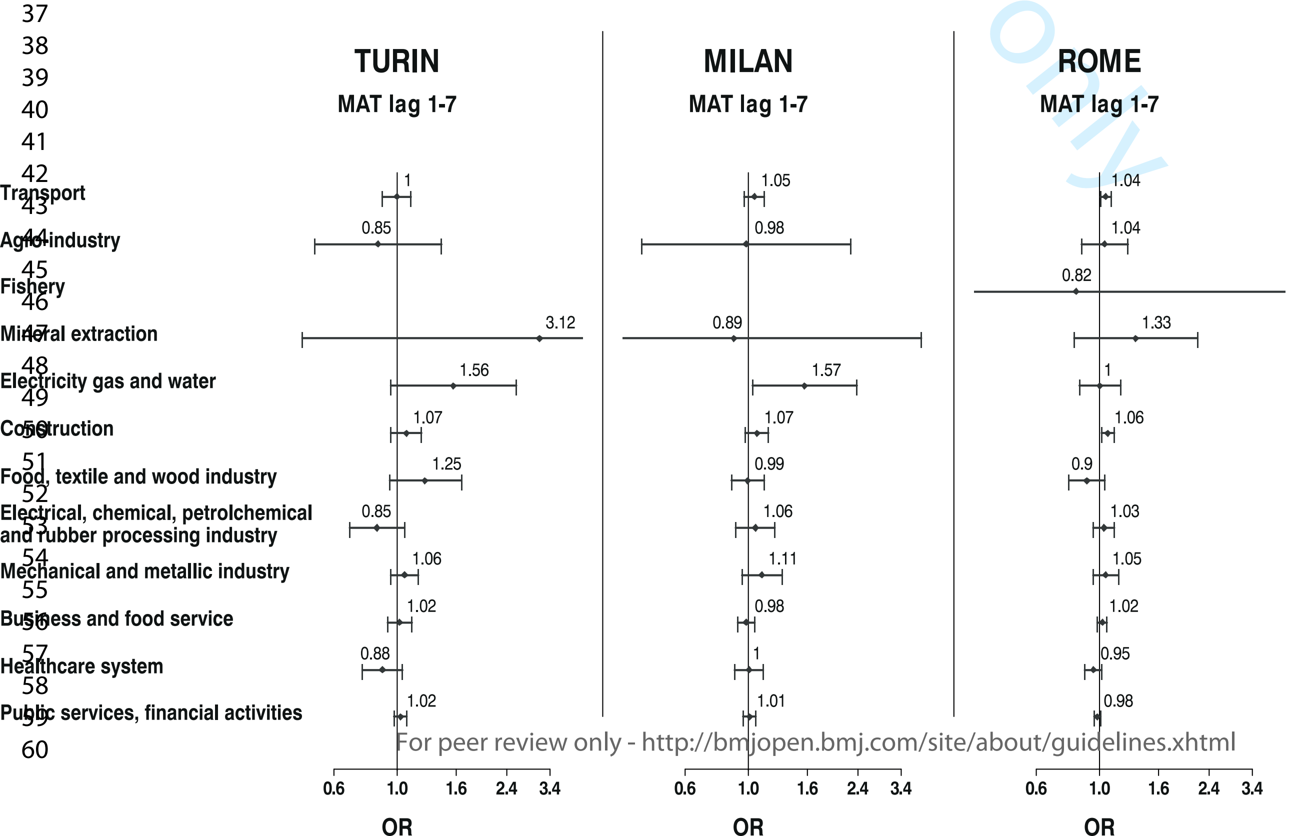
Figure 3. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase* by occupational activities, in *Transportation, Construction, Electricity gas and water* industries, during warm season (May-September) in Turin, Milan and Rome.

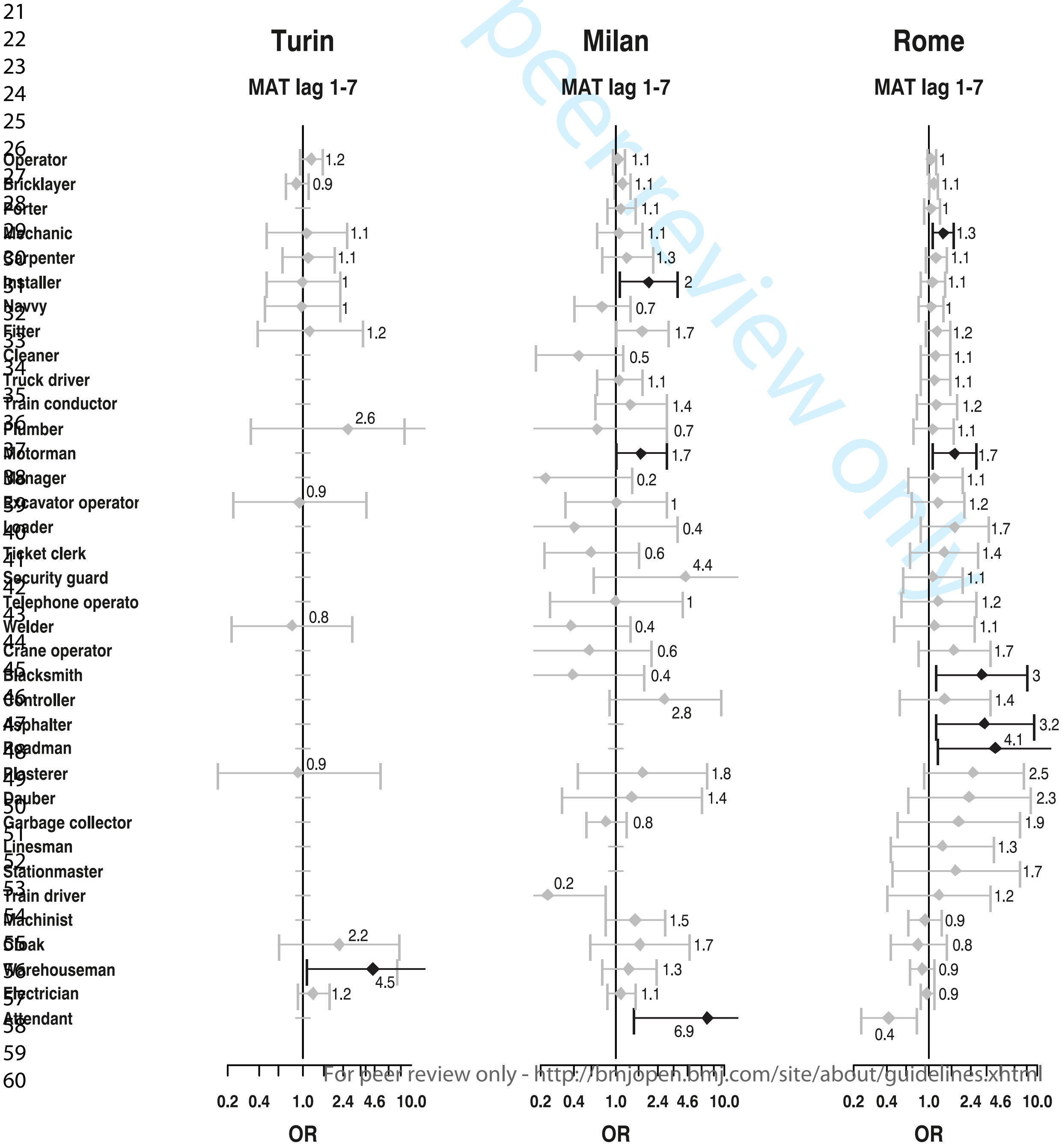
* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

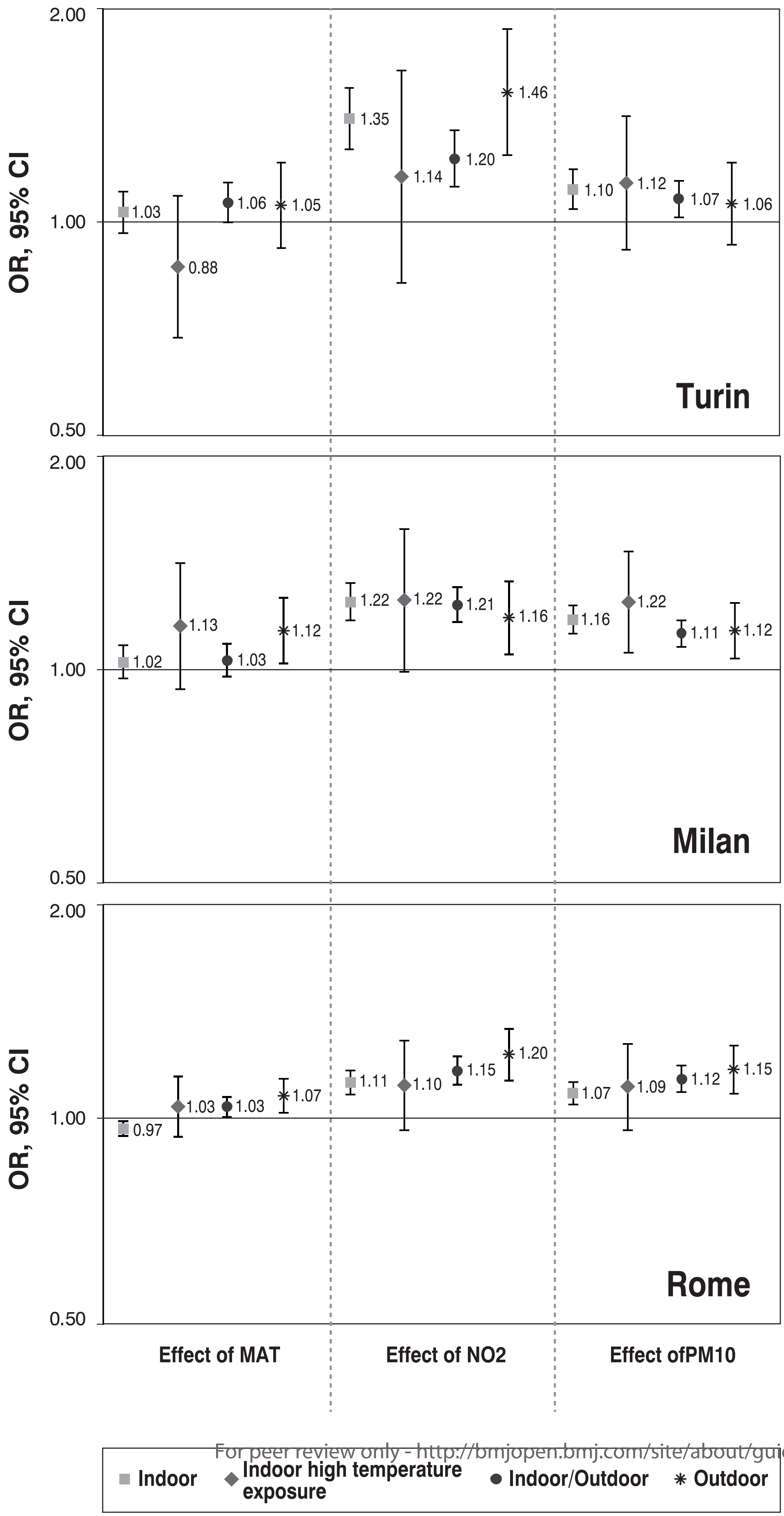
Figure 4. Odds Ratios of WRI for MAT*, NO_2§ and PM_{10}§ increases by INDOOR/OUTDOOR job activity during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT
§ *95° vs 25° percentile of the distribution of the both air pollutants in the three cities*


TEMPERATURE
Warm season
MAT
Cold season
TMAX
Turin
LAG 1-7
SHAPE non linear
Milan
LAG 1-7
SHAPE non linear
Rome
LAG 1-7
SHAPE linear
Turin
LAG 6-21
SHAPE non linear
Milan
LAG 6-21
SHAPE non linear
Rome
LAG 0-6
SHAPE non linear
PM10
Warm season
Cold season
Turin
LAG 0-6
SHAPE non linear
Milan
LAG 0-7
SHAPE non linear
Rome
LAG 0-7
SHAPE non linear
Turin
LAG 2-12
SHAPE linear
Milan
LAG 0-3
SHAPE linear
Rome
LAG 5-19
SHAPE linear
NO2
Warm season
Cold season
Turin
LAG 0-8
SHAPE linear
Milan
LAG 0-8
SHAPE non linear
Rome
LAG 0-8
SHAPE linear
Turin
LAG 0-4
SHAPE linear
Milan
LAG 0-3
SHAPE linear
Rome
LAG 1-4
SHAPE linear


TURIN
MAT lag 1-7
MILAN
MAT lag 1-7
ROME
MAT lag 1-7
Transport
Agro-industry
Fishery
Mineral extraction
Electricity gas and water
Construction
Food, textile and wood industry
Electrical, chemical, petrolchemical and rubber processing industry
Mechanical and metallic industry
Business and food service
Healthcare system
Public services, financial activities
1
0.85
3.12
1.56
1.07
1.25
0.85
1.06
1.02
0.88
1.02
1.05
0.98
0.89
1.57
1.07
0.99
1.06
1.11
0.98
1
1.01
1.04
1.04
0.82
1.33
1
1.06
0.9
1.03
1.05
1.02
0.95
0.98
0.6
1.0
1.6
2.4
3.4
OR


Turin
Milan
Rome
MAT lag 1-7
MAT lag 1-7
MAT lag 1-7
Operator
Bricklayer
Porter
Mechanic
Carpenter
Installer
Navvy
Fitter
Cleaner
Truck driver
Train conductor
Plumber
Motorman
Manager
Excavator operator
Loader
Ticket clerk
Security guard
Telephone operato
Welder
Crane operator
Blacksmith
Controller
Asphalter
Roadman
Plasterer
Dauber
Garbage collector
Linesman
Stationmaster
Train driver
Machinist
Cloak
Warehouseman
Electrician
Attendant
0.2 0.4 1.0 2.4 4.6 10.0
OR
0.2 0.4 1.0 2.4 4.6 10.0
OR
0.2 0.4 1.0 2.4 4.6 10.0
OR


OR, 95% CI
2.00
1.00
0.50
1.03
0.88
1.06
1.05
1.35
1.14
1.20
1.46
1.10
1.12
1.07
1.06
Turin
1.02
1.13
1.03
1.12
1.22
1.22
1.21
1.16
1.16
1.22
1.11
1.12
Milan
0.97
1.03
1.03
1.07
1.11
1.10
1.15
1.20
1.07
1.09
1.12
1.15
Rome
Effect of MAT
Effect of NO2
Effect ofPM10
Indoor
Indoor high temperature exposure
Indoor/Outdoor
Outdoor

eTable 1. Temperature and pollutants distribution in Turin, Milan and Rome by seasonal period, 2001–2010.

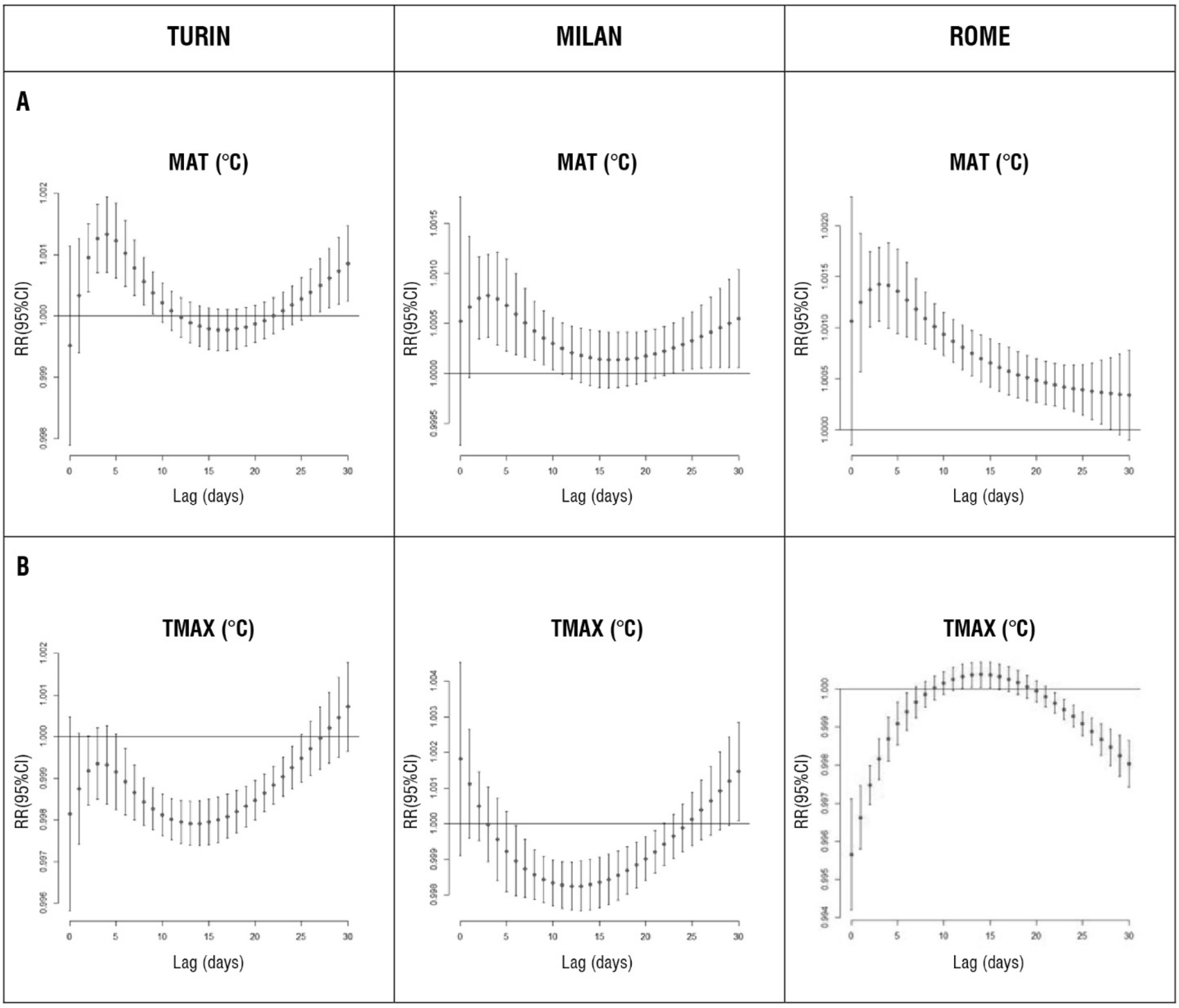
Exposure	Min	25° pctl	50° pctl	75° pctl	Max
WARM SEASON (May - September)					
Turin					
Daily maximum apparent temperature (°C)	9.0	22.3	26.3	30.1	39.7
PM_{10} (μg/m^3)	1.0	20.7	28.0	36.5	89.5
NO_2 (μg/m^3)	12.7	36.8	47.2	59.6	135.1
Milan					
Daily maximum apparent temperature (°C)	6.7	23.9	28.3	32.6	44.0
PM_{10} (μg/m^3)	4.9	22.5	29.6	38.5	87.4
NO_2 (μg/m^3)	11.2	33.9	43.4	53.8	128.1
Rome					
Daily maximum apparent temperature (°C)	12.4	24.4	28.3	32.2	39.7
PM_{10} (μg/m^3)	7.3	26.3	32.1	39.6	106.0
NO_2 (μg/m^3)	11.9	41.9	52.3	62.7	110.1
COLD SEASON (November – February)					
Turin					
Daily maximum temperature (°C)	-7.6	4.7	7.7	10.9	24.9
PM_{10} (μg/m^3)	8.0	50.5	75.0	102.0	242.0
NO_2 (μg/m^3)	19.9	64.9	79.0	92.9	197.9
Milan					
Daily maximum temperature (°C)	-3.2	5.3	8.3	11.3	21.6
PM_{10} (μg/m^3)	9.3	44.3	67.3	93.2	314.6
NO_2 (μg/m^3)	29.6	60.2	72.3	87.2	202.1
Rome					
Daily maximum temperature (°C)	5.5	10.3	12.6	14.5	23.2
PM_{10} (μg/m^3)	10.7	27.4	39.4	53.9	141.6
NO_2 (μg/m^3)	23.9	58.4	68.1	78.2	117.3

eTable 2. Pearson correlation coefficients between daily temperature and pollutants in both seasons for the three cities.

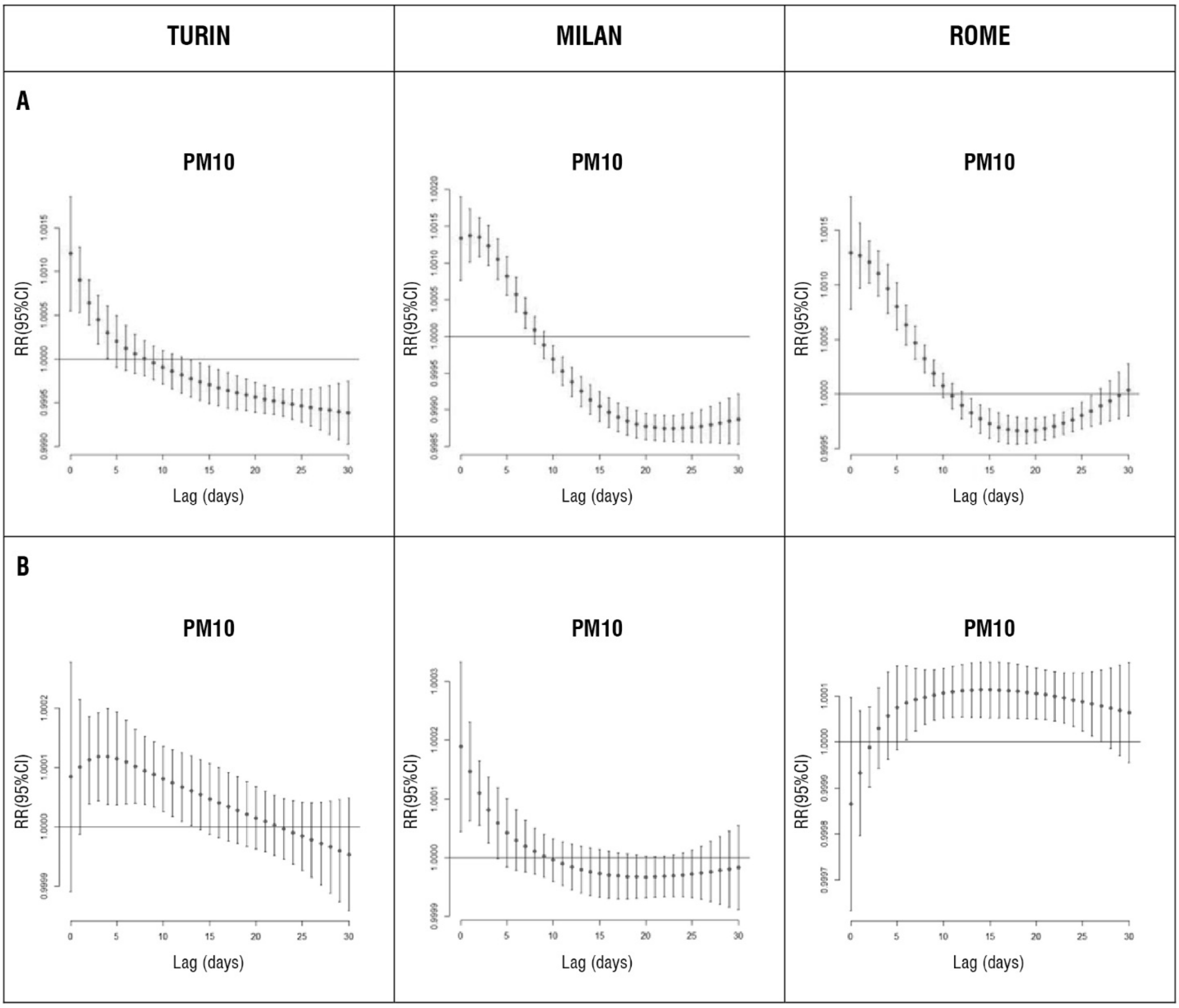
WARM SEASON				COLD SEASON			
TURIN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-6		TMAX lag 6-21	NO2 lag 0-4	PM10 lag 2-12
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.12*	1		NO2 lag 0-4	-0.42*	1	
PM10 lag 0-6	-0.01*	0.61*	1	PM10 lag 2-12	-0.20*	0.51*	1
MILAN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 6-21	NO2 lag 0-3	PM10 lag 0-3
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.22*	1		NO2 lag 0-3	-0.36*	1	
PM10 lag 0-7	0.28*	0.56*	1	PM10 lag 0-3	-0.29*	0.77*	1
ROME							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 0-6	NO2 lag 1-4	PM10 lag 5-19
MAT lag 1-7	1			TMAX lag 0-6	1		
NO2 lag 0-8	-0.08*	1		NO2 lag 1-4	-0.05	1	
PM10 lag 0-7	0.40*	0.49*	1	PM10 lag 5-19	-0.01	0.19*	1

* p-value < 0,05

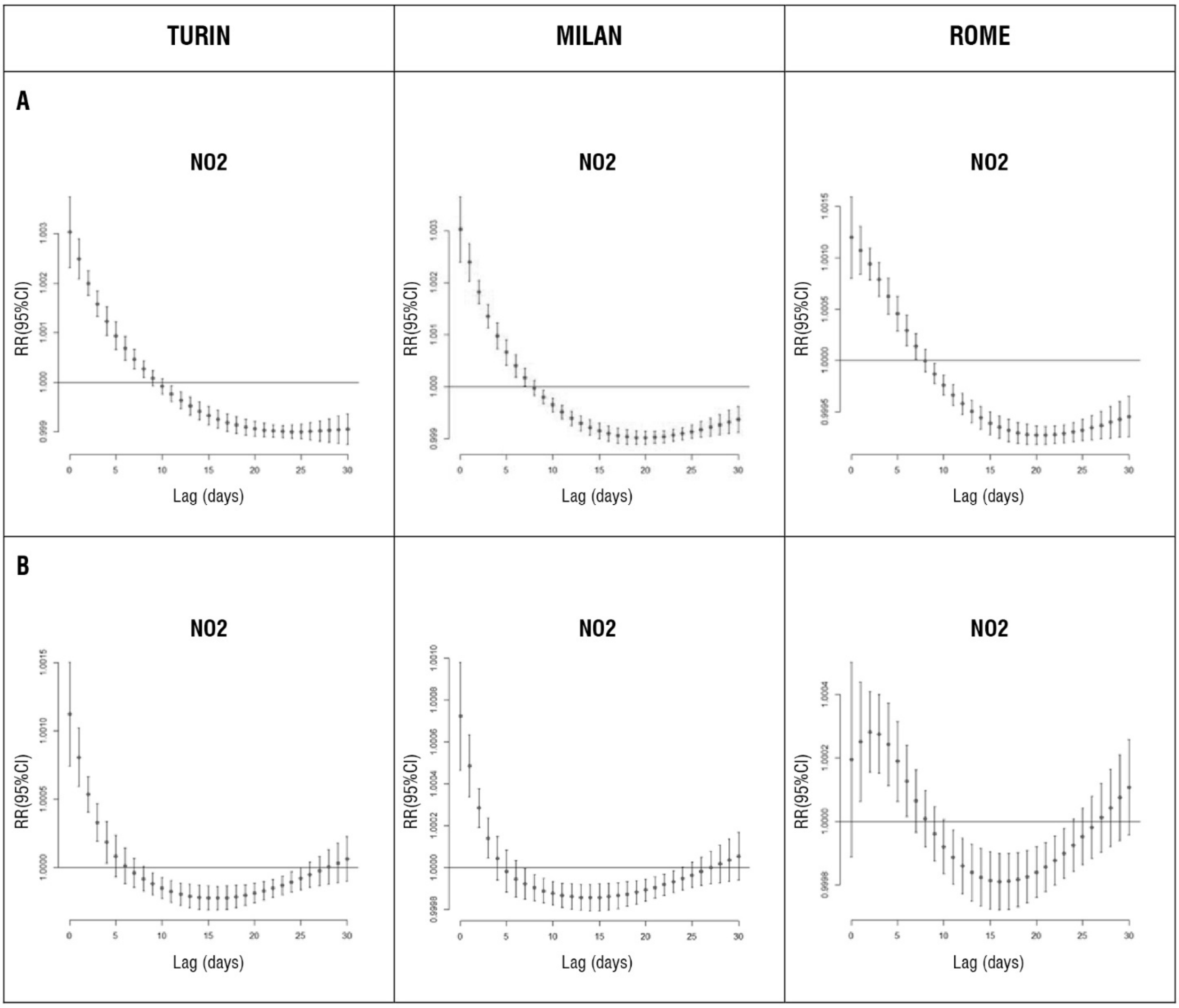
eFigure 1. Lag structure of Relative Risks (RR) of injury for 1 °C increase in temperature in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



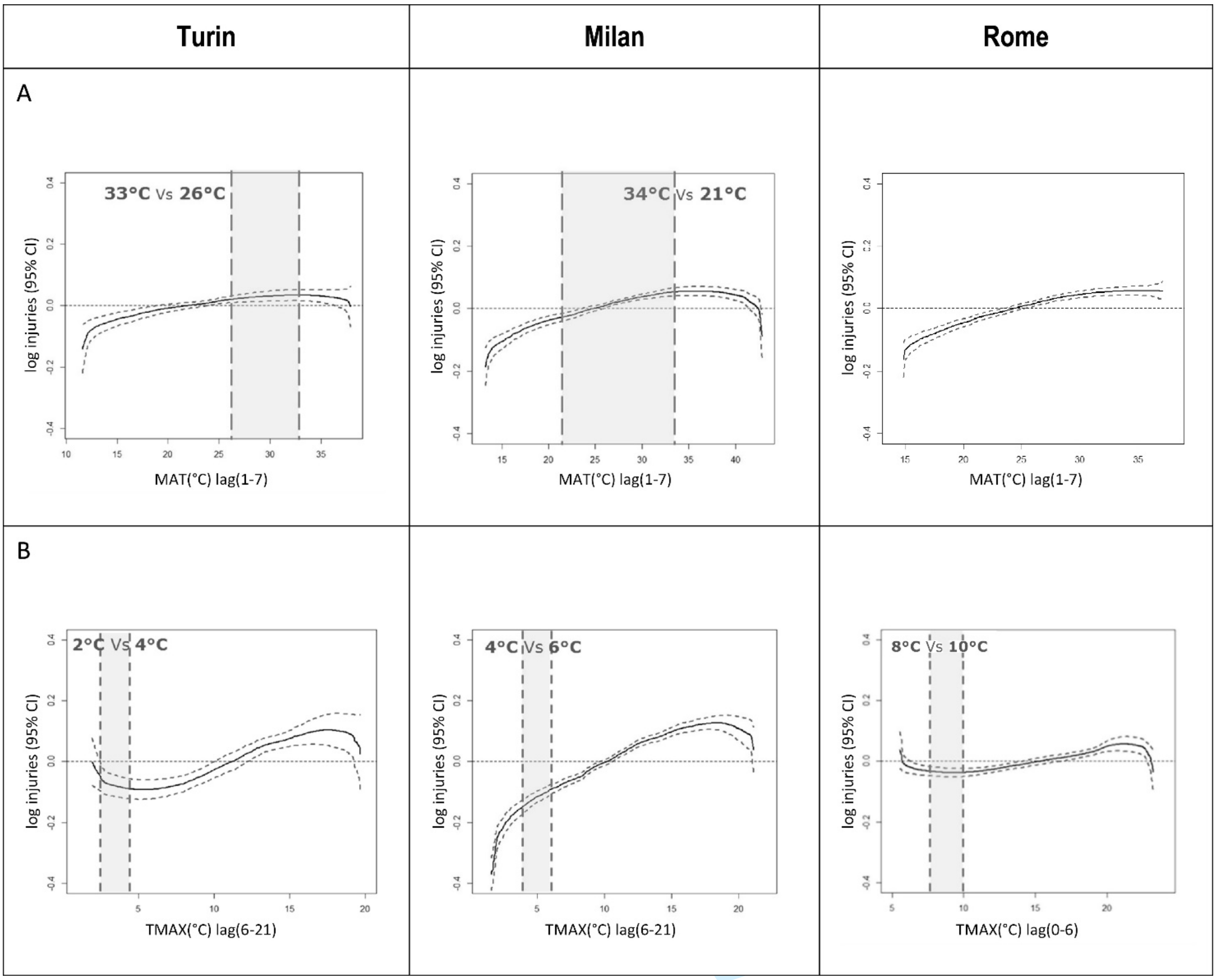
eFigure 2. Lag structure of Relative Risks (RR) of injury for 1 µg/m3 increase in PM_{10} in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



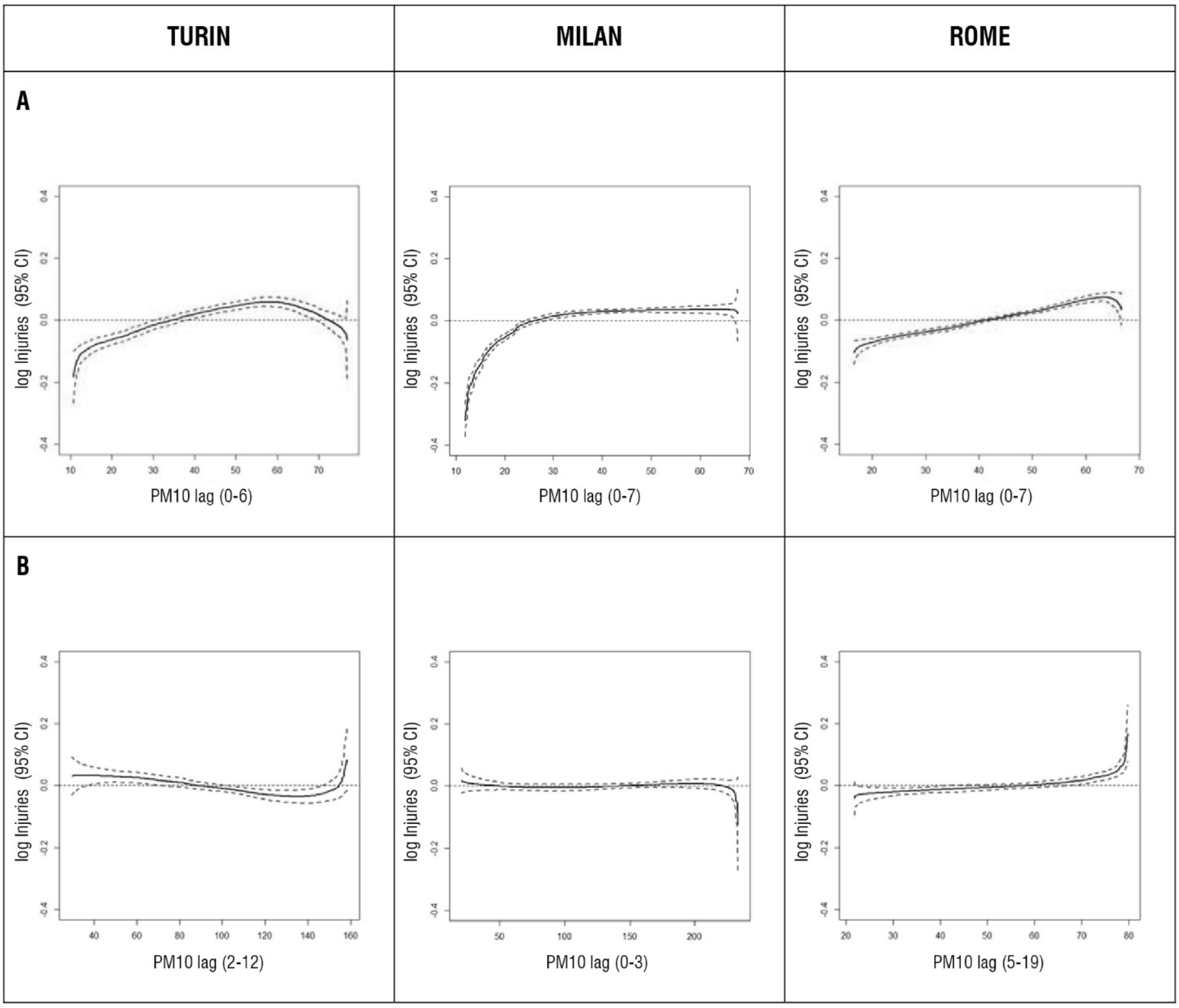
eFigure 3. Lag structure of Relative Risks (RR) of injury for 1 µg/m3 increase in NO_2 in the three cities obtained by distributed lag models, warm season (A) and cold season (B)



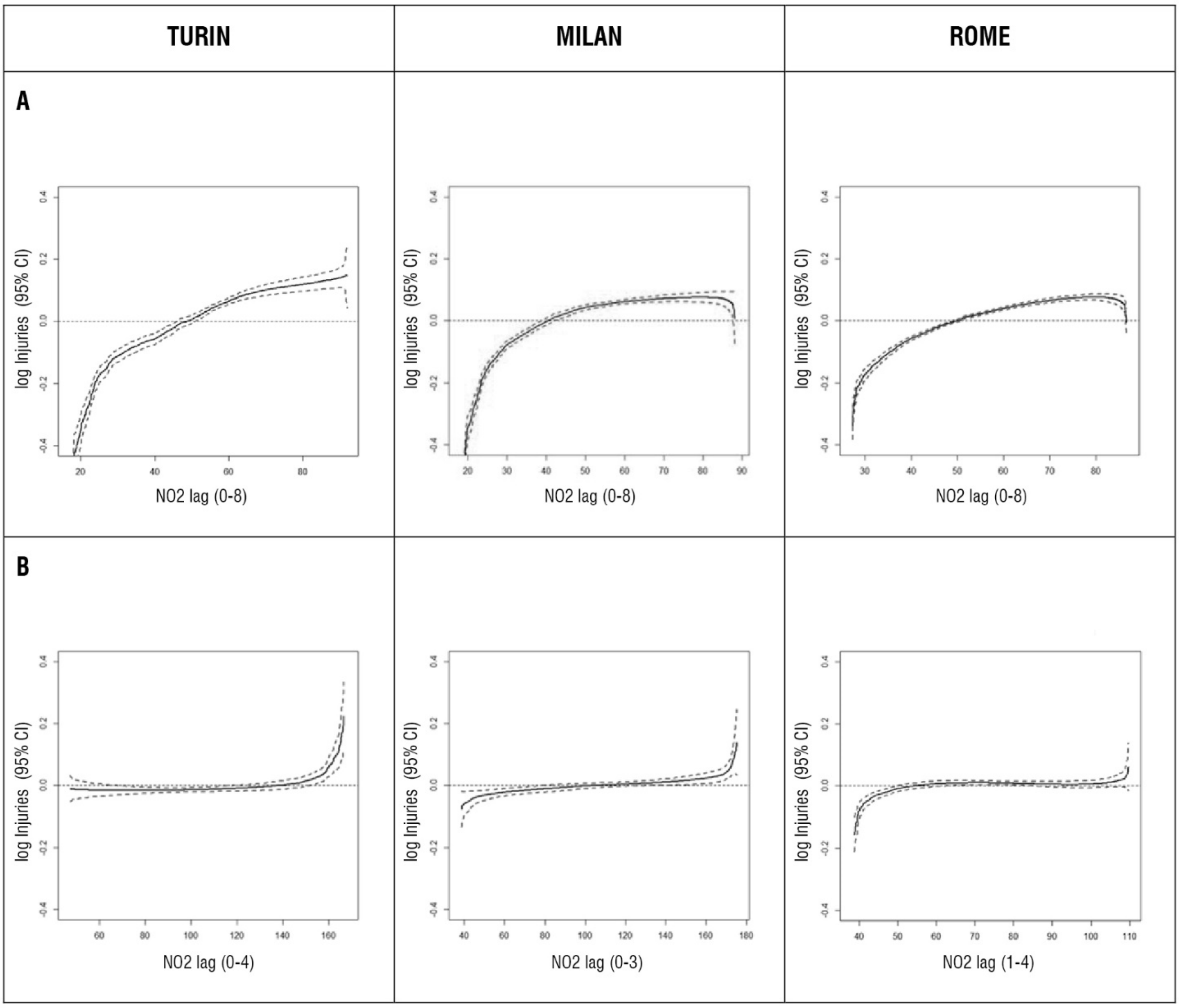
eFigure 4. The injury-temperature relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



eFigure 5. The injury–PM_{10} relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



eFigure 6. The injury–NO_2 relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



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Do exposure to outdoor temperatures, NO2 and PM10 affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023119.R1
Article Type:	Research
Date Submitted by the Author:	14-Feb-2019

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Primary Subject Heading:	Occupational and environmental medicine
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	air pollution, temperature, climate change, occupational health, work-related injuries, case crossover study

Title Page

Manuscript title: Do exposure to outdoor temperatures, NO_2 and PM_{10} affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010.

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Manuscript title: Do exposure to outdoor temperatures, NO_2 and PM_{10} affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010.

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Abstract

Objectives

Studies on the effect of temperature on rates of work-related injuries (WRI) are very recent, and are evolving in depth and scope. However less is known about potential effects of air pollutants. Our objective was to analyze the association between WRI and NO2, PM10 and air temperature in three major Italian cities, and to identify groups of workers more at risk in Italy.

Design time-stratified case-crossover study

Settings Milan, Turin, Rome, years 2001-2010

Participants A total of 468,816 WRI occurred between 2001-2010 in Milan, Turin and Rome were extracted from the Italian national workers' compensation authority (INAIL) database.

Main outcomes Associations between WRI and temperature, PM10, NO2, separately in the warm and in the cold season (WS, May-September; CS, November-February). Effect modification was studied by economic sector, occupational activity and indoor/outdoor job activity.

Results

Exposure to NO2 (lag 0-8) showed the highest effect on the risk of WRI,with ORs ranging from 1.20 (95% CI: 1.16-1.24) in Milan to 1.30 (95% CI: 1.24-1.37) in Turin in the WS. The effect of exposure to PM10 was milder but consistent across all cities: ORs from 1.09 (95% CI: 1.05-1.12) in Turin to 1.15 (95% CI: 1.11-1.18) in Rome. Temperature was associated with risk of WRI only among those working in construction (highest association in Rome 1.06; 95% CI: 1.01-1.12), transportation (highest association in Milan 1.05; 95% CI: 0.96-1.14) and the energy industry (highest association in Milan 1.57; 95% CI: 1.03-2.38) in the WS in all cities. A weak effect of low temperatures was observed in the CS only in Rome.

Conclusions

Exposures to NO2 resulted as strongest hazard for work related injuries, mainly in warm months, while the independent effect of temperature was significant only in specific subgroups of workers. These results could be considered to better plan safety prevention programs.

Keywords: air pollution; temperature; climate change; occupational health; work-related injuries; case crossover study

Strenghts and Limitations

- We used a very large dataset that was not derived from self-reported data
- We analysed data from three major Italian cities with different meteorological and pollution condition
- we estimated the independent effects of temperature and air pollution, controlling one for the other in the model
- daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL
- All exposure measures used were daily averages deriving from fixed points of measurement in the city

Background

Extreme weather events are becoming more frequent and intense as a result of climate change [1] and the relationship between extreme temperature and population health has been well documented.[2] Furthermore, air quality is influenced by a changing climate, which in turn impacts population health.[3]The association between outdoor temperature and air pollutants with mortality and morbidity in the general population has stimulated a large body of research, identifying susceptible subgroups, such as the elderly, people with chronic respiratory and cardiovascular diseases, and children.[4,5]

However, the consequences of climate and pollutants on work environments and their subsequent effects on job performance and safety are only recently coming to light.

Numerous factors such as worksite location and weather conditions may affect occupational exposure to air pollution; and likewise, indoor workplace environments may affect and exacerbate the adverse health effects of exposure to outdoor air pollutants. This is particularly a concern in workers with pre-existing health conditions and could theoretically lead to an increase in safety issues. The association between intense and prolonged occupational exposure to heat and health effects on workers is characterized by dehydration and spasms, increased perceived fatigue, exacerbating hazards resulting from sweaty palms, fogged-up safety glasses, dizziness, and reduced brain function. [7-11], reduced productivity and decreased reaction capacities.[6] Young, male workers and those in occupations requiring physical labor, and outdoor workers, are at higher risk of adverse impact because of their exposure to heat and humid conditions, as well as prolonged exposure to solar radiation and/or other artificial heat sources.[12-15] Furthermore, cultural social and ethnical characteristics of workers could play a significant role. [16] As well, workers exposed to extreme cold may be at risk of cold stress, increased cardiovascular and respiratory diseases risks, musculoskeletal and dermatological disorders, loss of dexterity and injuries related to hypothermia.[7,17]

There is good evidence of the negative effects of short-term exposure to PM_{10} on respiratory health, such as aggravated asthma, respiratory symptoms and an increase in hospital admissions.[18] Nitrogen dioxide (NO_2) is a strong respiratory irritant gas originating from high-temperature combustion; a large study has shown a positive association between daily increases of NO_2 and natural, cardiovascular, and respiratory mortality.[19] Also, air pollution has been shown to negatively affect other outcomes such as productivity of agricultural workers.[20]

In addition, levels of exposure to pollutants might also vary according to several factors, such as SES, educational level, air conditioning use, proximity to roadways, and work environment.[21] The warm season has been seen to be the strongest effect modifier of the effect of some pollutants on natural mortality;[22,23] this might be due to the fact that in summer, measured concentrations of air pollutants are more representative of true exposure because people spend more time outside and open windows more often.

A recently published review [24] summarized what is known about the heat and cold effects on work related injuries, and identified categories of workers at risk and evaluated heterogeneity and sources of bias of the included studies. Authors concluded that most studies had design limitations with regards to establishing a causal relationship and underlined the need for good quality studies that provide accurate estimates of relative risk of heat effects on occupational injuries.

The objective of this study is to estimate the short-term effects of summer and winter outdoor temperatures and air pollution on the risk of work related injuries, and to identify susceptible groups of workers.

Methods

Study population

We examined all work injuries that occurred between May and September and between November and February in the years 2001- 2010 in three major Italian cities: Milan, Turin and Rome.

Data were extracted from the Italian national workers' compensation authority (INAIL) database, which covers about 85% of Italian workers. For each injury episode that caused absences of three or more days, we gathered socio-demographic characteristics, occupation, and job title, and modalities and causes of the injury. Injuries in subjects younger than 17 years of age were excluded.

Meteorological and air pollution data

Rome, Milan and Turin are large metropolitan areas with different climatic conditions. Milan and Turin are located in Northern Italy and have a cold humid subtropical or mild continental climate, characterized by hot, humid summers with frequent thunderstorms and cold, damp winters often featuring fog in low-lying areas. Rome is located in central Italy 20 km from the Tyrrhenian Sea and has a typical Mediterranean climate with hot, dry summers and mild, wet winters.

Based on previous heat studies conducted in the same cities we chose maximum daily apparent temperature (MAT) [25-27] for the warm season (May-September), [28] and maximum daily temperature (TMAX) for the cold season (November-February) as indicators of temperature.[29] These were measured at the airport station closest to each city. With regards to air pollutants, we used the 24-hr mean daily value of nitrogen dioxide (NO_2) and of particulate matter with an aerodynamic diameter of 10 μm (PM_{10}). Data were extracted from the Regional Environmental Protection Agency (ARPA); values were obtained by averaging monitor-specific daily measurements available from different monitoring stations; we used city-specific daily mean values for all subjects.[30]

Statistical analysis

The analysis was organized in three steps. Because not much is already known about the relationship between work related injuries and temperature and air pollution variations, we first explored the city and season-specific lag structures of each exposure. We used a non-linear distributed lag model (DLNM),[31] allowing a maximum lag structure of 30 days, with the aim of selecting the lags showing the strongest association, using crossbasis centered on the median values of each exposure distribution using a natural cubic spline with df equals 4. As a second step we checked the linearity of the environmental exposure-injury risk relationship, at the lag defined by the previous step, through a Poisson generalized additive model, in each city and season. In both steps models were adjusted for long and seasonal trends using a triple interaction between year, month and day of the week, for holiday days and for influenza epidemics (only in cold season models).

As a third step the effect of environmental exposures on work-injury risk was evaluated using a time stratified case-crossover design separately for each city.[32] For each "case" (the day a work injury occurred) three more days were chosen as controls, matched by day of the week, month and year with the case day, to control for long-term trends, seasonality and day of the week. We estimated odds ratios (OR) and 95% confidence intervals (CI) through a conditional logistic regression model, further adjusted for holidays and influenza epidemics (only in the cold season). Models were exposure, season, and city specific. Lags and shape of the relationship were those defined in the previous two steps. Lagged exposure was computed as the average exposure in the days identified by the lag.

We adjusted one exposure with the others in the model only when their correlation was lower than 0.4.

We tested potential effect modification, of the environmental exposure-injury risk relationship by economic sector (using the Statistical Classification of Economic Activities in the European Community [NACE], Rev. 2 – 2008"), time spent outdoors or indoors (Indoor/Outdoor job activity) and occupational activity, including an interaction term between each variable and the exposure in the model.

Patient and Public Involvement

Patients and or public were not involved in this study

Results

Study Population

We analyzed a total of 468,807 work-related injuries, i.e about 52,000 per month independently by the season (Table 1).

Table 1. Injury distribution by workers' demographic and job characteristics, 2001-2010.

		Warm Season	Cold Season
Total : 468,807		262,804	206,003
Age group, n(%)			
	< 30	60,599 (23.0)	48,408 (23.5)
	30 - 50	158,086 (60.2)	121,997 (59.2)
	>50	44,119 (16.8)	35,598 (17.3)
Gender, n(%)			
	Male	165,054 (62.8)	124,671 (60.5)
	Female	97,750 (37.2)	81,332 (39.5)

Economic sector, n(%)		
Transport	31,914 (12.1)	24,257 (11.8)
Agro-industry	1,242 (0.5)	969 (0.5)
Fishery	2 (0.0)	2 (0.0)
Mineral extraction	179 (0.1)	140 (0.1)
Electricity gas and water	1,725 (0.7)	1,418 (0.7)
Construction	23,373 (8.9)	16,208 (7.9)
Food, textile and wood industry	6,588 (2.5)	5,264 (2.5)
Electrical, chemical, petrochemical and rubber processing industry	8,445 (3.2)	6,511 (3.2)
Mechanical and metallic industry	10,860 (4.1)	7,413 (3.6)
Business and food service	44,810 (17.0)	34,690 (16.8)
Healthcare system	14,719 (5.6)	11,980 (5.8)
Public services, financial activities	118,947 (45.3)	97,151 (47.2)
Indoor/Outdoor job activity, n(%)		
Indoor	105,215 (40.0)	87,578 (42.5)
Indoor high temperature exposure	7,099 (2.7)	5,669 (2.8)
Indoor/Outdoor	88,231 (33.6)	65,299 (31.7)
Outdoor	23,585 (9.0)	16,442 (8.0)
Missing	38,674 (14.7)	31,015 (15.0)

Meteorological and air pollutants data

Warm season

Rome and Milan showed a common median value of MAT of about 28°C, while Turin showed a median MAT of 26°C. Rome had the higher minimum value for MAT, (**eTable 1**, supplementary material). As for pollution, values were quite similar in the three cities; we observed a moderate correlation between PM_{10} and NO_2 ($\rho \geq 0.5$) in all cities and between MAT and PM_{10} ($\rho = 0.4$) in Rome (**eTable 2**, supplementary material).

Cold season

Rome was the warmest city with a median TMAX of 13°C, while Turin and Milan were cooler and had similar median TMAX values of about 8°C. We observed a minimum of -8°C for TMAX in Turin and of -3°C in Milan, while Rome never went below 5°C of TMAX (**eTable 1**, supplementary materials). As for air pollution we observed similar values of NO_2 in the three cities, and higher values of PM_{10} in Turin and Milan. (**eTable 1**, supplementary materials). We observed positive correlations between PM_{10} and NO_2 in Turin (ρ=0.5) and Milan (ρ=0.6) (**eTable 2**, supplementary material).

Lag structure and shape of the exposure-work injury relationship (step 1 and step2)

Analysis of the lag structure indicated a delayed effect on injury risk of all analysed exposures; during the warm period the greatest effects were observed within the first week after exposure, while in the cold period effects could persist up to 20 days. (**eFigure 1**, **eFigure 2**, **eFigure 3**, supplementary material). A summary, for all exposures, of chosen lags and of the shape of relationship (linear/non linear) with WRI risk were reported in Figure 1.

In the warm period the work-related injury/temperature relationship was linear in Rome (**eFigure 4**, supplementary materials) and non-linear in Turin and Milan. In these two cities we estimated ORs comparing city-specific MAT levels chosen in order to maximize the contrast. These points were identified by observing the injury-temperature relationship in eFigure4. In particular, we compared the 90th percentile (33°C) versus the 50th (26°C) in Turin and 90th percentile (34°C) versus the 10th (21°C) in Milan; results for Rome were reported for the interquartile range (32°C versus 24°C). As for air pollutants, the PM_{10}/WRI relationship was linear in Rome and nonlinear in Turin and Milan (**eFigure 5**, supplementary material), while the NO_2/WRI relationship was linear in Rome and Turin and non-linear in Milan (**eFigure 6**, supplementary material).

In the cold months, the WRI/temperature relationship was non-linear in the three cities (**eFigure 4**, supplementary material). As for the warm period we estimated ORs comparing city-specific TMAX's levels in order to maximize the effect in each city; in particular we compared the 10th percentile (4°C) versus the first percentile (2°C) in Turin, the 25th percentile (6°C) versus the 5th (4°C) in Milan and the 25th percentile (10°C) versus the 5th (8°C) in Rome. Air pollutants–WRI relationship was linear in all the three cities for both PM_{10} and NO_2. In both climatic periods we estimated effects comparing the 95th percentile versus the 25th when the relationship was non linear and for one unit increase when it was linear. Results were always reported for the 95th percentile versus the 25th (**eFigure 5**, **eFigure 6**, supplementary material).

Conditional logistic regression models (step 3)

In the warm season, the univariate analysis showed a positive association between WRI and MAT, PM_{10} and NO_2 in all cities. In the cold season, we observed an inverse association between WRI and TMAX and a positive one between WRI and NO_2 in all cities, and between WRI and PM_{10} only in Rome.

When adjusting temperature for one pollutant at a time in the warm months, the association with WRI resulted to be non-significant, while there was a positive significant effect when adjusting for temperature of both PM_{10} and NO_2 in all cities; in the cold months we observed a significant association of NO_2 with WRI in all cities, and of TMAX and PM_{10} in Rome. We reported only adjusted estimates. (Table 2)

Table 2. Adjusted Odds ratios (ORs) of WRI for temperature and air pollutants levels variations in Turin, Milan and Rome. Period 2001-2010.

Environmental exposures	OR (95% CI)	Comparison (percentile)
WARM SEASON *(May-September)* [a]		
Turin		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.02 (0.99, 1.06)	90th vs 50th
PM_{10} (μg/m^3) (Lag* 0-6) [c]	1.09 (1.05, 1.12)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.30 (1.24, 1.37)	95th vs 25th
Milan		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.01 (0.98, 1.04)	90th vs 10th
PM_{10} (μg/m^3) (Lag* 0-7) [c]	1.13 (1.10, 1.16)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.20 (1.16, 1.24)	95th vs 25th
Rome		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.00 (0.99, 1.02)	75th vs 25th
PM_{10} (μg/m^3) (Lag* 0-7) [c]	1.15 (1.11, 1.18)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.22 (1.16, 1.28)	95th vs 25th
COLD SEASON *(November – February)* [d]		
Turin		
Daily maximum temperature (°C) (Lag* 6-21) [b]	1.05 (0.93, 1.18)	1th vs 10th
PM_{10} (μg/m^3) (Lag* 2-12) [e]	0.98 (0.94, 1.02)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-4) [e]	1.11 (1.06, 1.17)	95° vs 25th
Milan		
Daily maximum temperature (°C) (Lag* 6-21) [b]	0.94 (0.92, 0.96)	5th vs 25th
PM_{10} (μg/m^3) (Lag* 0-3) [e]	1.00 (0.98, 1.03)	95th vs 25th

NO_2 (µg/m[3]) (Lag* 0-3) [e]	1.09 (1.06, 1.11)	95th vs 25th
Rome		
Daily maximum temperature (°C) (Lag* 0-6) [b]	1.02 (1.00, 1.04)	5th vs 25th
PM_{10} (µg/m[3]) (Lag* 5-19) [e]	1.05 (1.03, 1.08)	95th vs 25th
NO_2 (µg/m[3]) (Lag* 1-4) [e]	1.04 (1.02, 1.06)	95th vs 25th

[a] Final conditional regression model adjusted by holidays.
[b] Adjusted for NO2
[c] Adjusted for MAT
[d] Final conditional regression model adjusted by influenza epidemics and holidays.
[e] Adjusted for TMAX
* Lags expressed in days.

The effect of NO_2

Exposure to NO_2 showed the highest positive association with the risk of being injured at work in both seasons and in all cities. In the warm season, an increase of NO_2 from the 25th to the 95th percentile was associated with an increase in work injuries ranging between 1.20 (95% CI: 1.16-1.24) in Milan and 1.30 (95% CI: 1.24-1.37) in Turin; in the cold season the effect of NO_2 was lower, ranging between 1.04 (95% CI: 1.02-1.06) in Rome and 1.11 (95% CI: 1.06-1.17) in Turin. (Table 2) No effect modifiers of the NO_2/WRI relationship in either season were found.

The effect of PM_{10}

An increase of PM_{10} from the 25th to the 95th percentile in the warm season was associated with an increase in WRI ranging between 1.09 (95% CI: 1.05-1.12), in Turin, and 1.15 (95% CI: 1.11-1.18), in Rome. During the cold season, we found a significant effect of PM_{10} only in Rome with a 1.05 (95% CI: 1.03-1.08) increase in WRI. (Table 2) No effect modifiers of the PM_{10}/WRI relationship in either season were found.

The effect of temperature

No significant association between temperature and injury risk was observed in the warm season overall, but for workers in the following economic sectors: transportation (Turin 1.00 - *95% CI: 0.89-1.13;* Milan 1.05; *95% CI: 0.96-1.14; Rome 1.04*; *95% CI: 1.00-1.09)*, construction (Turin 1.07 - *95% CI: 0.95-1.21;* Milan 1.07; *95% CI: 0.97-1.17; Rome 1.06*; *95% CI: 1.01-1.12)* and energy industries (Turin 1.56 - *95% CI: 0.95-2.58;* Milan 1.57; *95% CI: 1.03-2.38; Rome 1.00*; *95% CI: 0.85-1.18)* (Figure 2). However the effect was modest.

The association between WRI and temperature or air pollutants by occupational activity was estimated only for those injuries occurred in one of the three economic sectors with a significant association between temperature and WRI, and only in the warm season (Transportation, Construction, and Electricity Gas and Water - Figure 2). In order to have enough statistical power we aggregated into a single category all those occupational activities for which less than 20 injuries were reported in at least one city. Blacksmith, mechanic, installer, motor worker, road worker, warehouse worker, attendant and asphalter were the only activities for which we observed a significant effect of temperature on WRI. The highest effects were observed for road workers (*OR:4.05 - 95% CI:1.20-13.66),* warehouse workers (*OR:4.45 - 95% CI:1.10-18.02)* and attendants (*OR:6.91 - 95% CI:1.42-33.57)*. (Figure 3)

We also observed a significant effect of MAT on those working outdoors in Milan (OR:1.12 - *95% CI: 1.02-1.23)* and Rome (OR:1.07 - *95% CI: 1.01-1.12)*, and among those working both outdoors and indoors only in Rome (OR:1.03 - *95% CI: 1.00-1.06)*. No effect was observed among those working only indoors (Figure 4).

In the cold season, a decrease of TMAX from 4°C to 2°C was associated with a weak and not significant increase in WRI (OR: 1.02; 95% CI: 1.00-1.04) in Rome (Table 2) while in Turin and Milan no effect was observed. No effect modifiers of TMAX-WRI in the cold season were found.

Discussion

This is the first study conducted in Italy to analyze the independent effects of temperature (hot and cold) and air pollutants on the risk of work-related injuries. The strongest effects on WRI risk was due to exposure to NO_2 in the warm season, with a WRI risk up to 1.3 times higher when NO_2 levels increased from the 25th to 95th percentile of its city-specific distribution.

In general we observed a significant association between exposure to NO_2 and WRI in both seasons, in all job categories, and in all cities; and between PM_{10} and WRI only in Rome during the cold season. Temperature showed a significant effect only in specific occupational activities during the warm season (May to September).

The relationship between NO_2 and the occurrence of work related injuries had a similar shape in the three cities in both periods (**eFigure 6**, supplementary material). As expected, NO_2 values were lower in the warm than in the cold season, with median values in the three cities of about 50 μg/m^3 and 73 μg/m^3 respectively (eTable 1). Despite this, there was a stronger association between NO_2 and WRI in the warm than in the cold season, possibly due to a "ceiling effect", given that levels of NO_2 in the cold season are always higher. It is also noticeable that the effect of NO_2 remained constant regardless of economic sector or occupational activity. Although an established causal association between NO2 exposure and occupational injuries risk has not been provided by epidemiological published analyses in our knowledge, our results could suggest a mechanism of action through a decreased level of attention and lower capacity of reaction to unexpected dangerous situations at work. Furthermore, the ascertained evidences of an association between NO2 exposure (with a role of high temperature as modifying effects) and cardiovascular and respiratory health effects, [33] could allow to suppose a risk of injuries at work as secondary effect of this correlation.

PM_{10} levels showed a similar trend as NO_2, with lower levels in the warmer months and higher levels and a low day by day variability in the cold period. Only in Rome, the southern of the three cities, PM_{10} showed lower and more variable levels in the cold period. (**eTable 1**, supplementary material); and it is interesting to observe that an increase of PM_{10} is associated to an increase in WRI in this season only in Rome. In the warm months the effect of PM_{10} is consistent in the three cities, but lower then that of NO2. On days in which PM_{10} levels reach the 95th percentile of the city specific distribution the risk of WRI is 10% higher than on days when PM_{10} levels are around their 25th percentile.

The similar shape of the pollutant-WRI risk both among cities and among pollutants supports our study's robustness Furthermore, what is known about the short term health effects of exposure to air pollutants [33-35] made it reasonable to think of potential effects on work-related injuries. Some previous studies have analyzed health-related outcomes in specific categories of workers, particularly those exposed to urban stressors, such as street vendors and policemen, and they showed some effects on cardiovascular diseases, pregnancy outcomes, and respiratory diseases.[36-40,20] One study measured a negative economic impact of exposure to air pollutants in agriculture workers, finding lower productivity on more polluted days.[20] Finally, a recent study [36] tried to measure the association between occupational exposure to ozone and respiratory diseases, with no conclusive results.

Mounting experimental evidence suggests that, in addition to the cardiopulmonary system, the brain may be a target of air pollution. Specific mental and neurological disorders, such as depression and headache, as well as suicide have all been linked to ambient air pollution.[41,42] Inhaled concentrated ambient particulate matter may translocate to the brain and produce neuroendocrine and neuropathological alterations.[43] The lag of these effects was short, two or three days;[44] so it is reasonable to think that these exposures might explain the association between pollution and work related injuries.

As for heat, our study showed an increase of injuries only among bricklayers, blacksmiths, mechanics, installers and asphalters working in transportation, construction and energy economic sectors , and in the more generic group of those working outdoor or performing both outdoor and indoor tasks, but not among those who work only indoors. These results are consistent with previous studies.[45,46, 28]

It is interesting that the unadjusted OR of MAT on WRI during the warm season ranged from 1.03 in Rome (75° vs 25° percentile, range=8°C) to 1.06 in Turin (90° vs 50° percentile, range=7°C), but these effects lowered to 1.01 and became not significant when adjusting for air pollution. The observed confounding of temperature by pollution should be considered when comparing our results to unadjusted estimates of temperature-WRI associations from other published studies.

Two previous studies conducted in Italy [47] and in Australia [45] found an inverse U-shaped relationship between high temperatures and WRI in summer, with maximum risk on warm days but not on extremely hot days. The relationship observed in Turin and Milan (eFigure4) also suggest a similar trend, even if quite weak. Also, the values of MAT in correspondence of which the highest rates of injuries were observed were 33°C-34°C, while they remained stable or decreased afterwards. In Rome, which experiences warmer summer conditions than Milan and Turin, we found a linear relationship consistent with what was observed in two recent studies conducted in Melbourne and in Quebec. [46,12] Different population characteristics as well as temperature distributions might influence these differences between cities. Furthermore, it has to be considered that the trend in the effects observed in Milan and Turin might be biased by the lower statistical power in the highest extremes of the temperature distribution, due to the fewer days observed with those temperature levels. This is not the case in Rome where temperatures even above 34°C are adequately represented.

Ambient heat might increase metabolic heat that is normally produced in activities requiring physical exertion; accordingly we have observed an effect of heat in more physically demanding economic sectors and occupational activities. We categorized workers according to three different criteria as suggested in a previous study:[12] economic sector, occupational activity and outdoor or indoor location. This classification allowed us to measure both the risk associated with physical demands (economic sector and occupational activity) and the gradient of exposure to outdoor heat. Our results showed higher susceptibility among those working outdoors and no effects on those working only indoors, confirming that those working outdoors are more susceptible to pollution and temperatures exposure. However, when analysing single occupational activities, we found that among the most susceptible there were some (mechanics, warehouse workers and attendants) who spend more time indoor than outdoor but still require high physical exertion. Strenuous activity, and use of heavy impermeable personal protective clothing might increase metabolic heat and increase the risk of injuries. This might suggest that the level of physical strength required by the occupation might be an important effect modifier to be taken into account for heat-related risk, independent of work location.[12]

Our study also examine the effect of temperature and air pollutants in the cold season. As for pollution, the effect is lower than in summer, probably because the exposure level is constantly higher; this explain the low and not significant relative risks in the cold season. As for temperature, we did not observe an effect of cold. A previous study conducted in Tuscany, in the center of Italy, found significant cold effects on outdoor occupational injuries especially among agricoltures and in drivers of vehicles other than cars [48].

An important strength of this study is that we estimated the independent effects of temperature and air pollution, controlling one for the other in the model. Also, we used a very large dataset that was not derived from self-reported data. However, our study presents some limits. The study population was drawn from the Italian public insurance system database that covers all work-related injuries due to violent causes that leads to death, permanent disability or temporary total disability lasting at least three days, and all occupational diseases. It is remarkable to consider that workers covered by the public insurance system for injuries and occupational diseases make up approximately 80-85% of the whole workforce in Italy. However, daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL. Some occupational activities, such as firefighters and the armed forces, benefit from a specific welfare system in Italy and are not included in the analyzed dataset. The distribution of daily injury claims by economic sector varies greatly and the relatively small numbers in some sectors dictates a cautious interpretation of results for less represented subgroups.

All exposure measures used were daily averages deriving from fixed points of measurement in the city, implying each worker was attributed the same level of exposure independently of his location in the city at the moment of injury, thus having a potential bias in exposure due to different temperatures and pollutants within the city on a given day. However, the error associated with this generalization in exposure is considered to be low.[49] Finally collinearity among NO_2 and PM_{10} didn't allow to adjust one pollutant for the other, so that the estimate of pollutant effect might be confounded by concomitant exposure to the other one. This limit is proper of almost all air pollution studies.

Conclusions

Our results suggest that exposure to nitrogen dioxide in the warm months strongly increase the risk of work related injuries among all categories of workers. Nitrogen dioxide also showed a significant effect in the cold season, but of lower intensity. These results suggest the need to further look into this association, to confirm our findings and to better understand the underlying mechanisms. Our results also show that , after removing the confounding effect of co-exposure to air pollution, the exposure to high temperature represents a risk only among workers who have heavier work loads and among those who spend most of their time outdoors. Finally our results confirms that in Italy, which is a Mediterranean country with a generally mild climate, ambient exposures represent a hazard for work related injuries only during the warmer months.

These results contribute to the increasing knowledge about the association between temperature and work related injuries, and add new evidence about the potential effects of pollutants that have not yet been studied in Italy except on very specific subgroups.

Identifying specific subgroups of workers as the most susceptible to these specific exposures is crucial information for public health organizations in order to properly target prevention plans.

Abbreviations

WRI, work related injuries;

PM_{10}, particulate matter with an aerodynamic diameter of 10 µm or less;

NO_2, nitrogen dioxide;

MAT, maximum apparent temperature;

TMAX, maximum temperature;

DLNM, non-linear distributed lag model;

OR, odd ratio;

CI, confidence interval.

Declarations

Acknowledgments

Authors aknowledge Dr. Simona Vecchi for her suggestions in the final revision of the manuscript; Giuseppe Campo and Fabio Cosimi (INAIL, Rome) for supporting in the retrieving and interpretation of injuries data and Julie Sawitzke for her carful editing and English review.

Funding

The study was carried out within “Cambiamenti climatici, inquinamento atmosferico e pollini: Modello integrato di monitoraggio dell’esposizione ambientale, allerta, sorveglianza rapida sanitaria e promozione di misure di prevenzione per ridurre l’impatto sulla salute”funded by CCM – Ministero della Salute.

Availability of data and materials

The data that support the findings of this study are available from *Occupational and Environmental Medicine, Epidemiology and Hygiene Department, Italian Workers’ Compensation Authority (INAIL), Rome, Italy* but restrictions apply to the availability of these data, which were used within the collaboration for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request. and with permission of INAIL.

Authors’ contributions

PS conceptualized and designed the study, drafted the manuscript. FA carried out the statistical analyses, reviewed and revised the manuscript. AM and MB contributed to the draft, critically reviewed the manuscript. MD critically reviewed the manuscript. PM collaborated to conceptualize and to desig the study, reviewed and revised the manuscript. All authors read and approved the final manuscript as submitted.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests to disclose.

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Figures:

Figure 1. Graphical summary of lags and shapes of exposures/WRI relationship (linear/non linear) by season and city.

Figure 2. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase*, by economic sectors, during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

Figure 3. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase* by occupational activities, in *Transportation, Construction, Electricity gas and water* industries, during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

Figure 4. Odds Ratios of WRI for MAT*, NO_2§ and PM_{10}§ increases by "Indoor/Outdoor job activity" during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT
§ *95° vs 25° percentile of the distribution of the both air pollutants in the three cities*

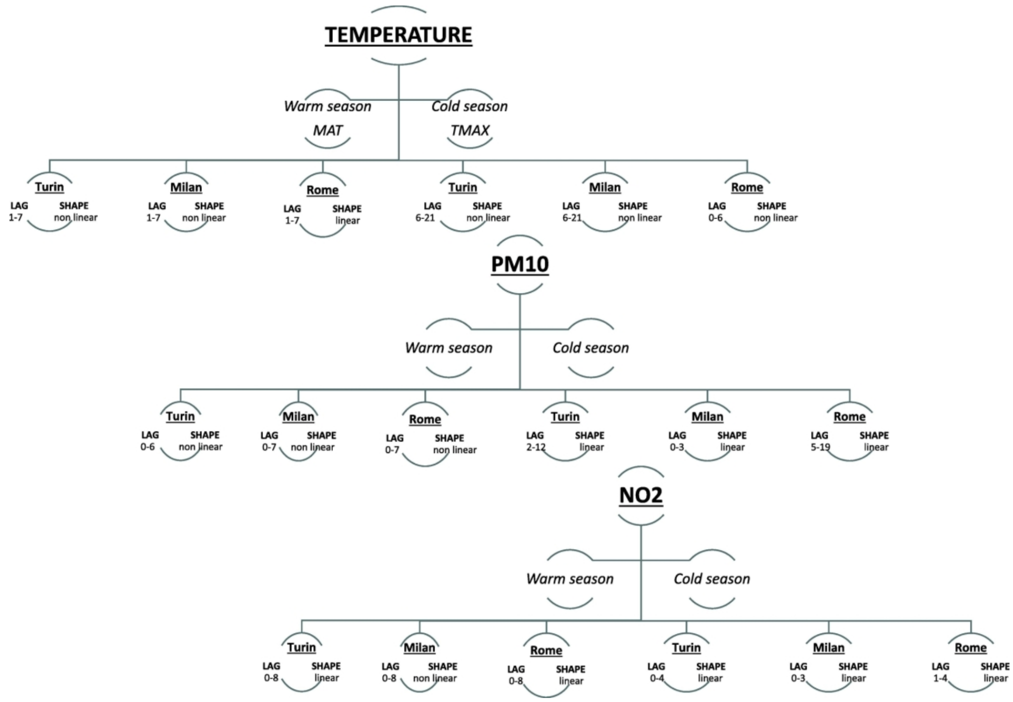

Figure 1

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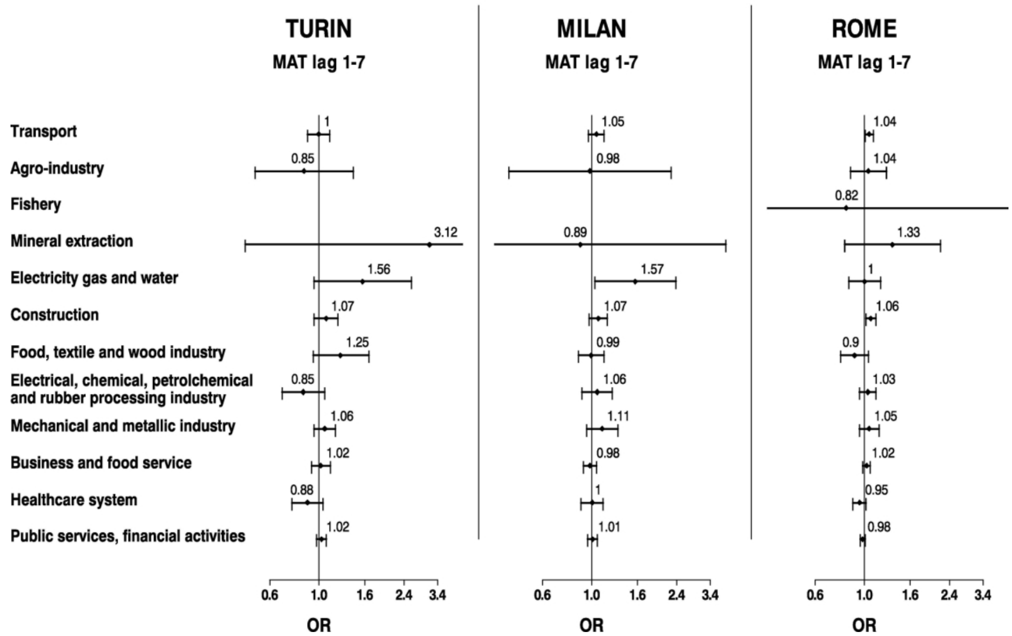

Figure 2

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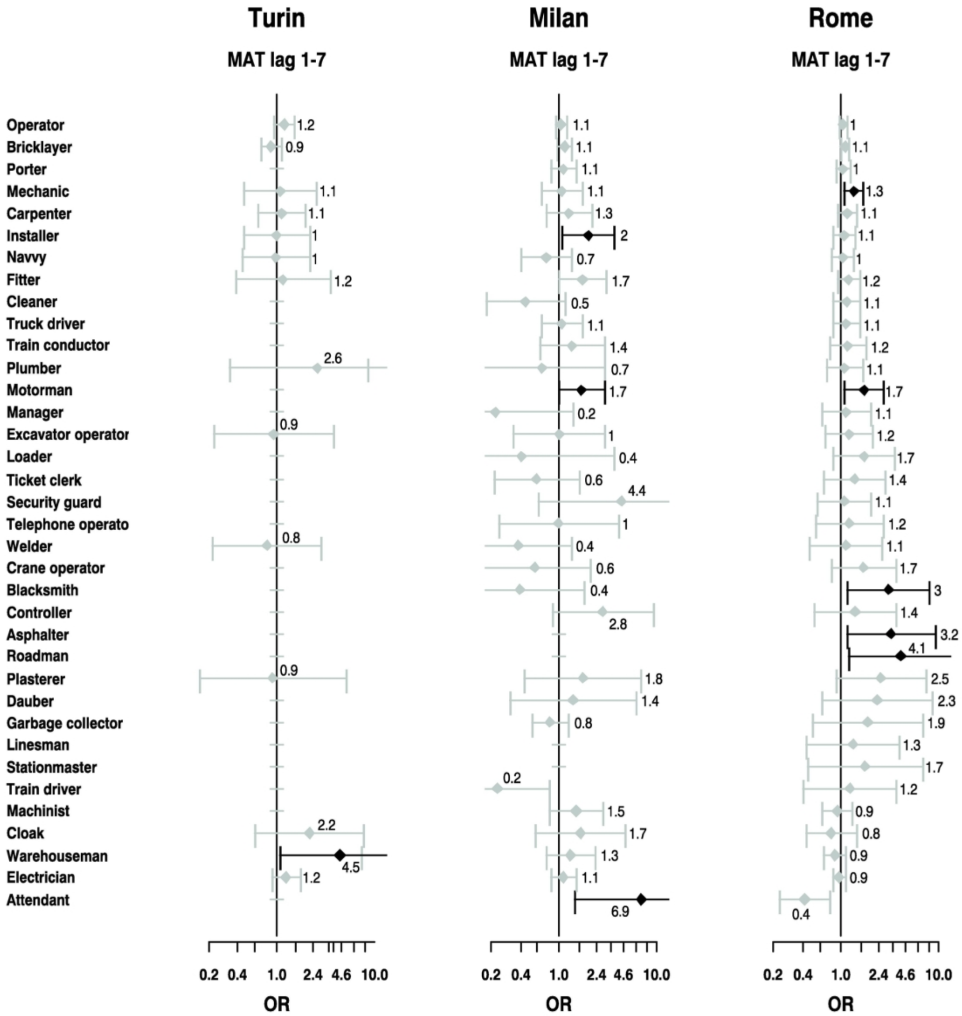

Figure 3

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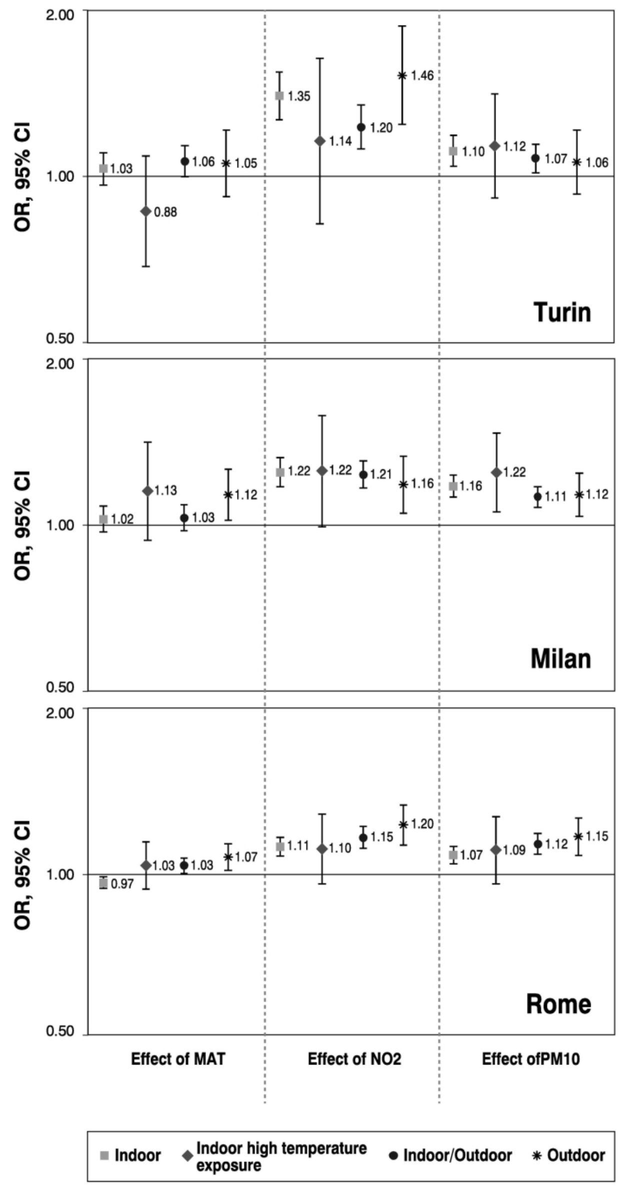

Figure 4

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eTable 1. Temperature and pollutants distribution in Turin, Milan and Rome by seasonal period, 2001–2010.

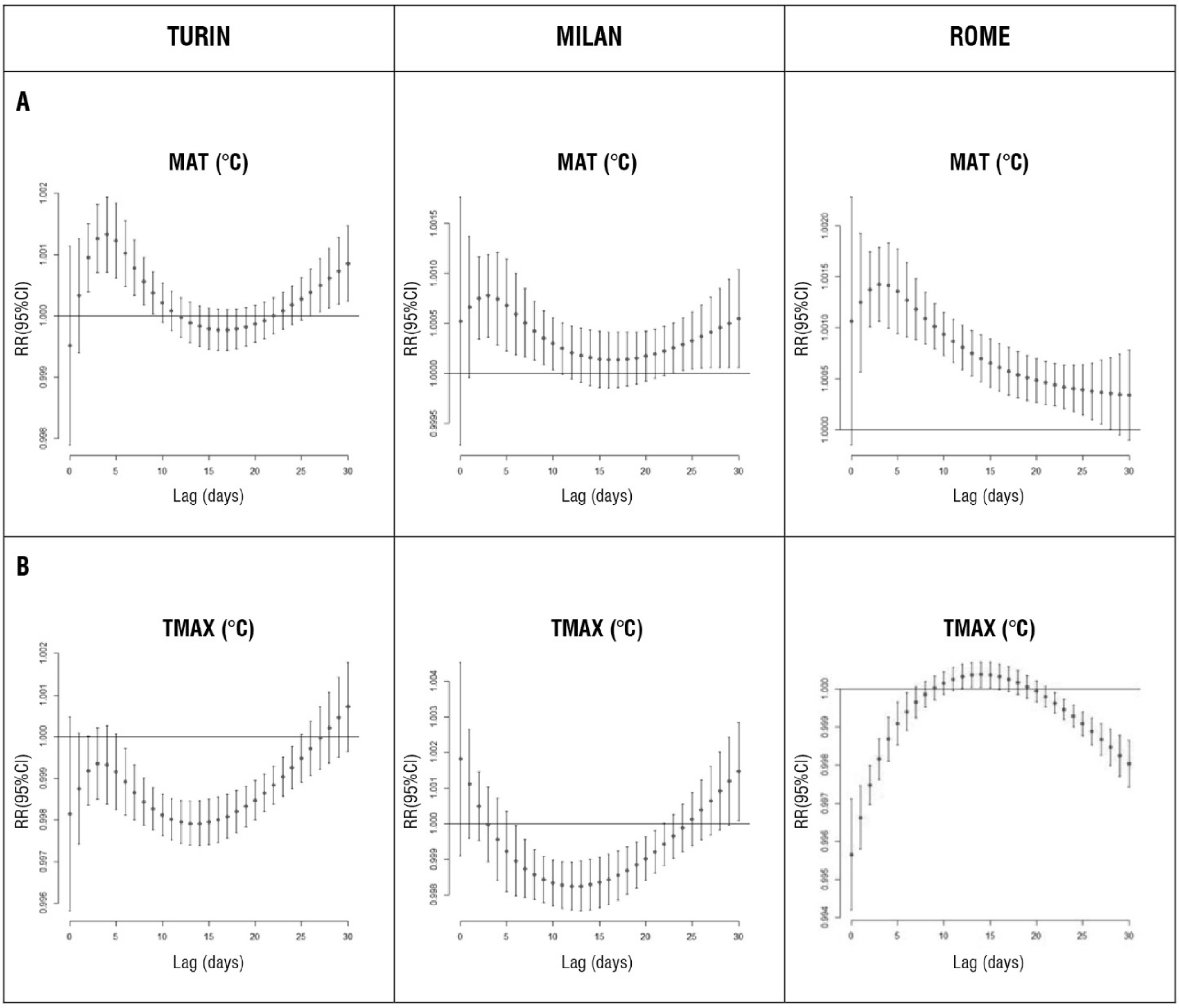
Exposure	Min	25° pctl	50° pctl	75° pctl	Max
WARM SEASON (May - September)					
Turin					
Daily maximum apparent temperature (°C)	9.0	22.3	26.3	30.1	39.7
PM_{10} (μg/m^3)	1.0	20.7	28.0	36.5	89.5
NO_2 (μg/m^3)	12.7	36.8	47.2	59.6	135.1
Milan					
Daily maximum apparent temperature (°C)	6.7	23.9	28.3	32.6	44.0
PM_{10} (μg/m^3)	4.9	22.5	29.6	38.5	87.4
NO_2 (μg/m^3)	11.2	33.9	43.4	53.8	128.1
Rome					
Daily maximum apparent temperature (°C)	12.4	24.4	28.3	32.2	39.7
PM_{10} (μg/m^3)	7.3	26.3	32.1	39.6	106.0
NO_2 (μg/m^3)	11.9	41.9	52.3	62.7	110.1
COLD SEASON (November – February)					
Turin					
Daily maximum temperature (°C)	-7.6	4.7	7.7	10.9	24.9
PM_{10} (μg/m^3)	8.0	50.5	75.0	102.0	242.0
NO_2 (μg/m^3)	19.9	64.9	79.0	92.9	197.9
Milan					
Daily maximum temperature (°C)	-3.2	5.3	8.3	11.3	21.6
PM_{10} (μg/m^3)	9.3	44.3	67.3	93.2	314.6
NO_2 (μg/m^3)	29.6	60.2	72.3	87.2	202.1
Rome					
Daily maximum temperature (°C)	5.5	10.3	12.6	14.5	23.2
PM_{10} (μg/m^3)	10.7	27.4	39.4	53.9	141.6
NO_2 (μg/m^3)	23.9	58.4	68.1	78.2	117.3

eTable 2. Pearson correlation coefficients between daily temperature and pollutants in both seasons for the three cities.

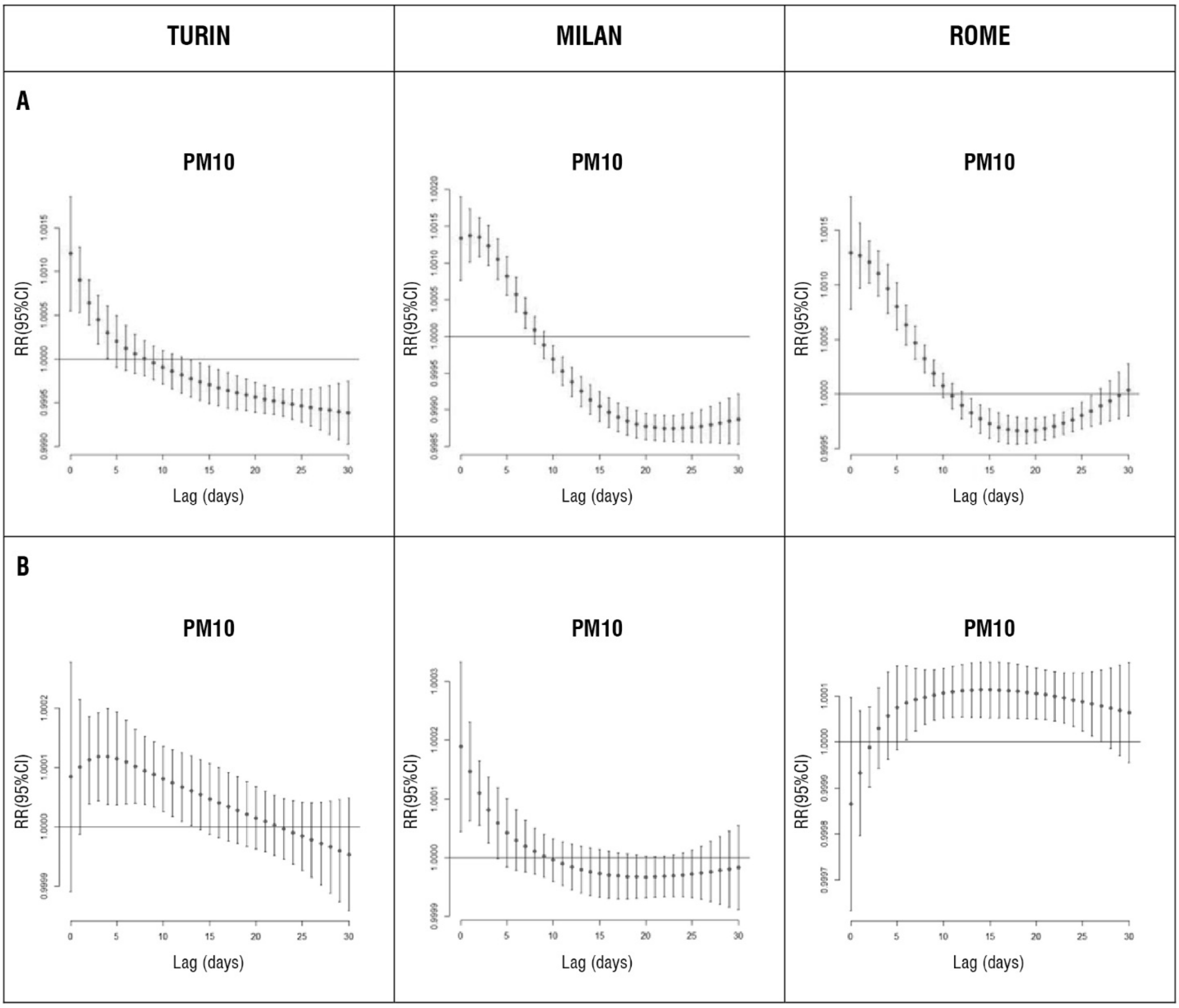
WARM SEASON				COLD SEASON			
TURIN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-6		TMAX lag 6-21	NO2 lag 0-4	PM10 lag 2-12
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.12*	1		NO2 lag 0-4	-0.42*	1	
PM10 lag 0-6	-0.01*	0.61*	1	PM10 lag 2-12	-0.20*	0.51*	1
MILAN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 6-21	NO2 lag 0-3	PM10 lag 0-3
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.22*	1		NO2 lag 0-3	-0.36*	1	
PM10 lag 0-7	0.28*	0.56*	1	PM10 lag 0-3	-0.29*	0.77*	1
ROME							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 0-6	NO2 lag 1-4	PM10 lag 5-19
MAT lag 1-7	1			TMAX lag 0-6	1		
NO2 lag 0-8	-0.08*	1		NO2 lag 1-4	-0.05	1	
PM10 lag 0-7	0.40*	0.49*	1	PM10 lag 5-19	-0.01	0.19*	1

* p-value < 0,05

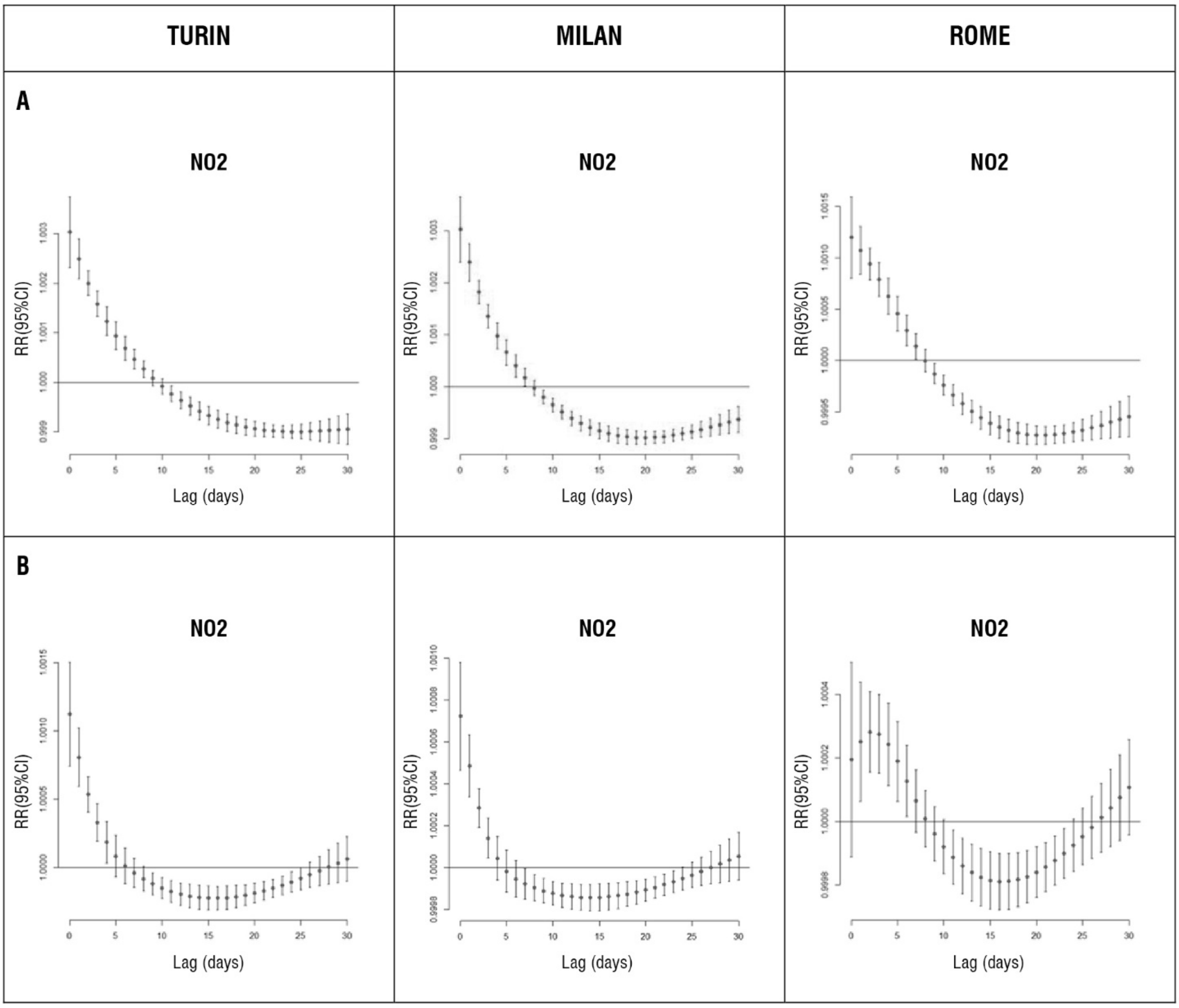
eFigure 1. Lag structure of Relative Risks (RR) of injury for 1 °C increase in temperature in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



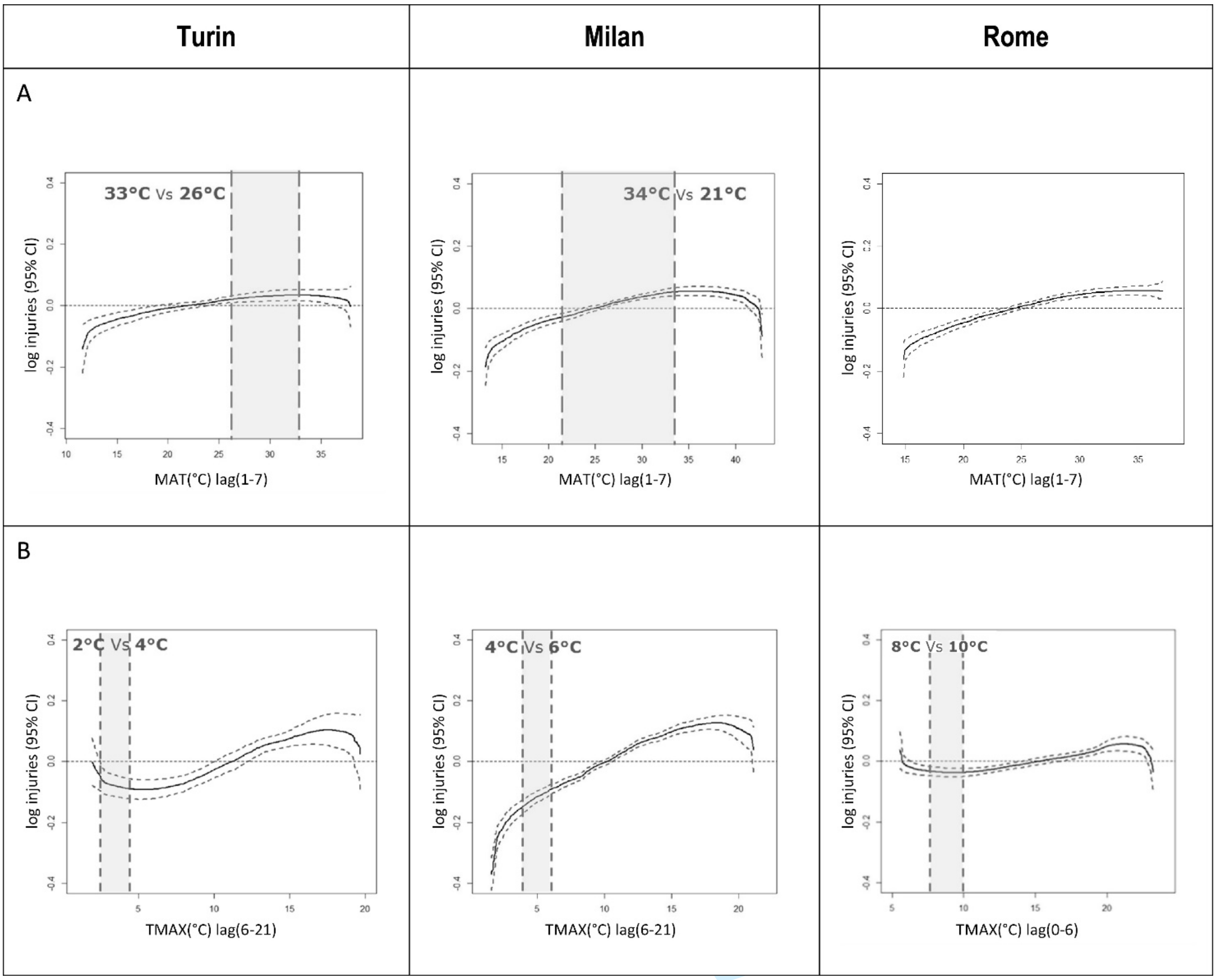
eFigure 2. Lag structure of Relative Risks (RR) of injury for 1 µg/m3 increase in PM_{10} in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



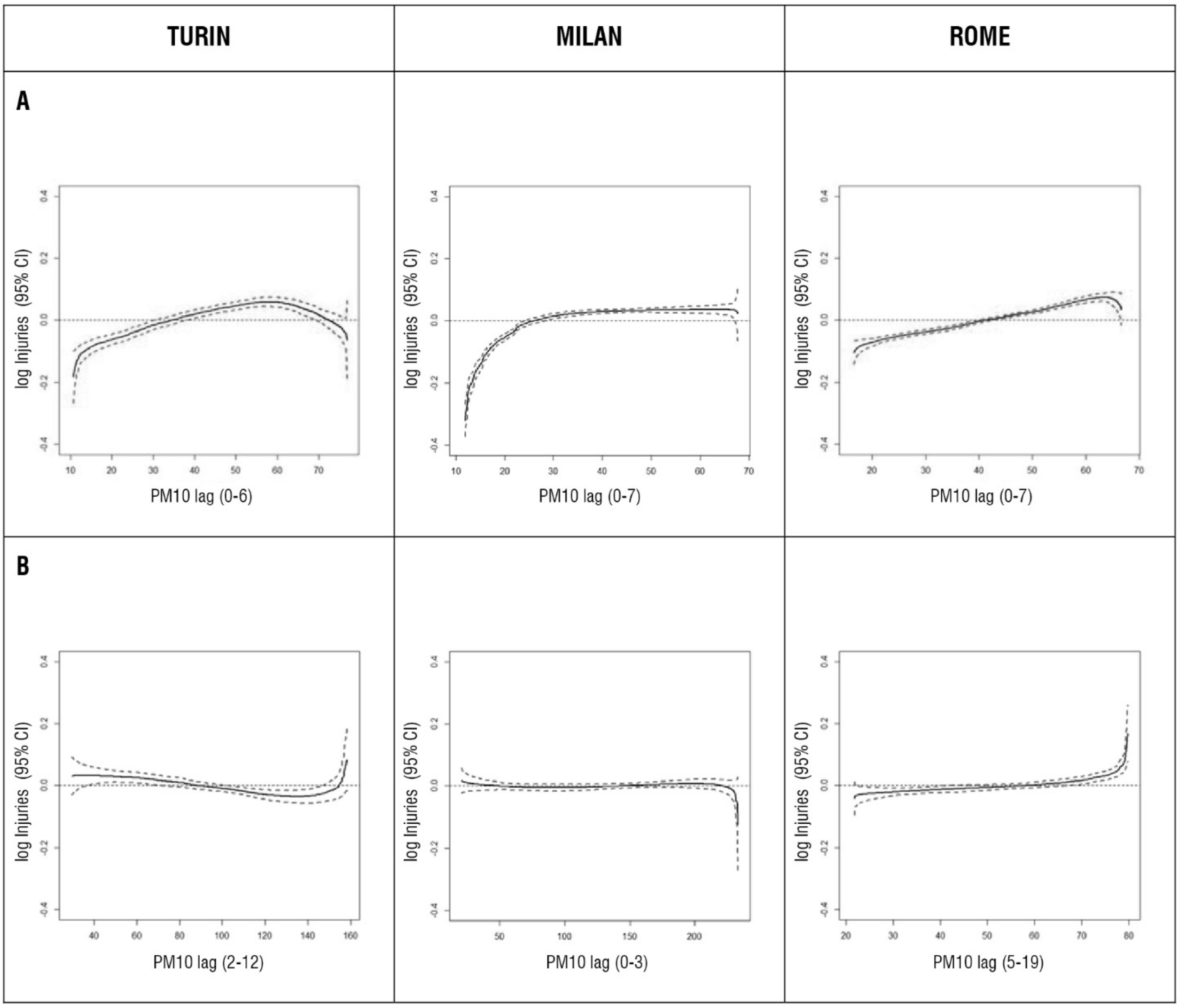
eFigure 3. Lag structure of Relative Risks (RR) of injury for 1 µg/m3 increase in NO_2 in the three cities obtained by distributed lag models, warm season (A) and cold season (B)



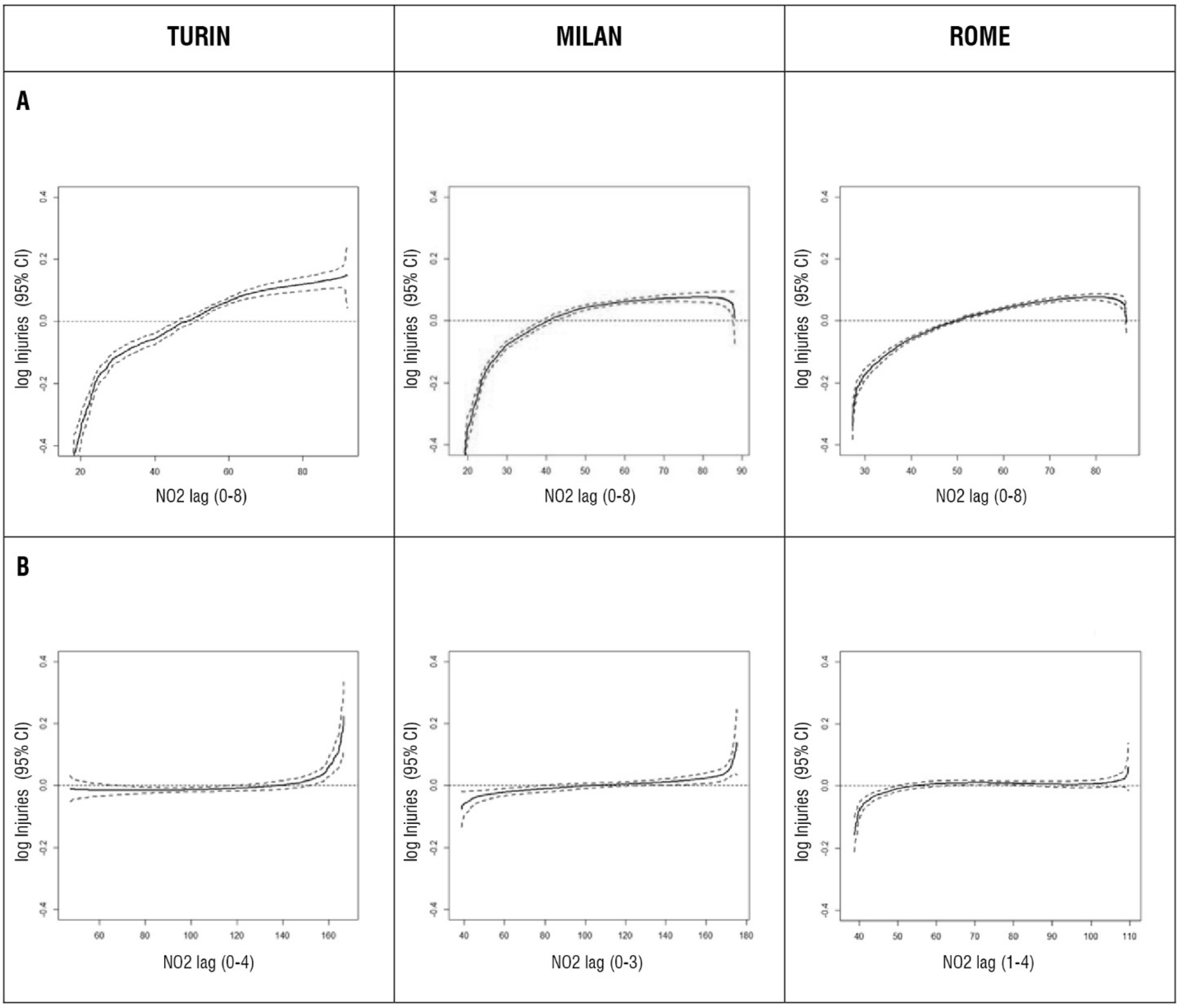
eFigure 4. The injury-temperature relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



eFigure 5. The injury–PM_{10} relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



eFigure 6. The injury–NO_2 relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



BMJ Open

Do exposure to outdoor temperatures, NO2 and PM10 affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010.

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023119.R2
Article Type:	Research
Date Submitted by the Author:	19-Jun-2019
Complete List of Authors:	Schifano , Patrizia ; Dipartimento di Epidemiologia del Servizio Sanitario Regionale del Lazio, Epidemiology asta, federica; Dipartimento di Epidemiologia del Servizio Sanitario Regionale del Lazio, Epidemiology Marinaccio, Alessandro; Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro, bonafede, michela; Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro Davoli, Marina; Dipartimento di Epidemiologia del Servizio Sanitario Regionale del Lazio, Epidemiology Michelozzi, Paola; Dipartimento di Epidemiologia del Servizio Sanitario Regionale del Lazio, Epidemiology
Primary Subject Heading:	Occupational and environmental medicine
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	air pollution, temperature, climate change, occupational health, work-related injuries, case crossover study

Title Page

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Manuscript title: Do exposure to outdoor temperatures, NO_2 and PM_{10} affect the work-related injuries risk? A case-crossover study in three Italian cities, 2001-2010.

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Abstract

Objectives

Studies on the effect of temperature on rates of work-related injuries (WRI) are very recent, and are evolving in depth and scope. However less is known about potential effects of air pollutants. Our objective was to analyze the association between WRI and NO_2, PM_{10} and air temperature in three major Italian cities, and to identify groups of workers more at risk in Italy.

Design time-stratified case-crossover study

Settings Milan, Turin, Rome, years 2001-2010

Participants A total of 468,816 WRI occurred between 2001-2010 in Milan, Turin and Rome were extracted from the Italian national workers' compensation authority (INAIL) database.

Main outcomes Associations between WRI and temperature, PM_{10}, NO_2, separately in the warm and in the cold season (WS, May-September; CS, November-February). Effect modification was studied by economic sector, occupational activity and indoor/outdoor job activity.

Results

Exposure to NO_2 (lag 0-8) showed the highest effect on the risk of WRI,with ORs ranging from 1.20 (*95% CI: 1.16-1.24*) in Milan to 1.30 (*95% CI: 1.24-1.37*) in Turin in the WS. The effect of exposure to PM_{10} was milder but consistent across all cities: ORs from 1.09 (*95% CI: 1.05-1.12*) in Turin to 1.15 (*95% CI: 1.11-1.18*) in Rome. Temperature was associated with risk of WRI only among those working in construction (highest association in Rome *1.06*; *95% CI: 1.01-1.12)*, transportation (highest association in Milan 1.05; *95% CI: 0.96-1.14)* and the energy industry (highest association in Milan 1.57; *95% CI: 1.03-2.38)* in the WS in all cities. A weak effect of low temperatures was observed in the CS only in Rome.

Conclusions

Exposures to NO_2 resulted as strongest hazard for work related injuries, mainly in warm months, while the independent effect of temperature was significant only in specific subgroups of workers. These results could be considered to better plan safety prevention programs.

Keywords: air pollution; temperature; climate change; occupational health; work-related injuries; case crossover study

Strenghts and Limitations

- We used a very large dataset that was not derived from self-reported data
- We analysed data from three major Italian cities with different meteorological and pollution condition
- we estimated the independent effects of temperature and air pollution, controlling one for the other in the model
- daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL
- All exposure measures used were daily averages deriving from fixed points of measurement in the city

Background

Extreme weather events are becoming more frequent and intense as a result of climate change [1] and the relationship between extreme temperature and population health has been well documented.[2] Furthermore, air quality is influenced by a changing climate, which in turn impacts population health.[3]The association between outdoor temperature and air pollutants with mortality and morbidity in the general population has stimulated a large body of research, identifying susceptible subgroups, such as the elderly, people with chronic respiratory and cardiovascular diseases, and children.[4,5]

However, the consequences of climate and pollutants on work environments and their subsequent effects on job performance and safety are only recently coming to light.

Numerous factors such as worksite location and weather conditions may affect occupational exposure to air pollution; and likewise, indoor workplace environments may affect and exacerbate the adverse health effects of exposure to outdoor air pollutants. This is particularly a concern in workers with pre-existing health conditions and could theoretically lead to an increase in safety issues. The association between intense and prolonged occupational exposure to heat and health effects on workers is characterized by dehydration and spasms, increased perceived fatigue, exacerbating hazards resulting from sweaty palms, fogged-up safety glasses, dizziness, and reduced brain function, reduced productivity and decreased reaction capacities.[6-11] Young, male workers and those in occupations requiring physical labor, and outdoor workers, are at higher risk of adverse impact because of their exposure to heat and humid conditions, as well as prolonged exposure to solar radiation and/or other artificial heat sources.[12-15] Furthermore, cultural social and ethnical characteristics of workers could play a significant role. [16] As well, workers exposed to extreme cold may be at risk of cold stress, increased cardiovascular and respiratory diseases risks, musculoskeletal and dermatological disorders, loss of dexterity and injuries related to hypothermia.[7,17]

There is good evidence of the negative effects of short-term exposure to PM_{10} on respiratory health, such as aggravated asthma, respiratory symptoms and an increase in hospital admissions.[18] Nitrogen dioxide (NO_2) is a strong respiratory irritant gas originating from high-temperature combustion; a large study has shown a positive association between daily increases of NO_2 and natural, cardiovascular, and respiratory mortality.[19] Also, air pollution has been shown to negatively affect other outcomes such as productivity of agricultural workers.[20] To the best of our knowledge, there is a lack of study on the association between air pollution and occupational injuries. Only recently, acute neuropsychological effects have been studied on humans by Sunyer et al.,2017 [21] showing an acute effect of air pollution on fluctuations in attention in children that probably arises through the same mechanism as the long-term association. A recent review [22] on this topic stated there is consistent evidence from animal studies showing impairments for short term memory due to air pollution exposure these deteriorations could be involved also as potential explanation of work-related injuries. Another potential mechanism of action that could be involved occurs through acute cardiovascular events triggered by air pollution [23] and leading to a decreased level of attention and lower capacity of reaction to unexpected dangerous situations at work as an acute secondary effect of this correlation.

In addition, levels of exposure to pollutants might also vary according to several factors, such as SES, educational level, air conditioning use, proximity to roadways, and work environment.[24]

The warm season has been seen to be the strongest effect modifier of the effect of some pollutants on natural mortality;[25,26] this might be due to the fact that in summer, measured concentrations of air pollutants are more representative of true exposure because people spend more time outside and open windows more often.

A recently published review [27] summarized what is known about the heat and cold effects on work related injuries, and identified categories of workers at risk and evaluated heterogeneity and sources of bias of the included studies. Authors concluded that most studies had design limitations with regards to establishing a causal relationship and underlined the need for good quality studies that provide accurate estimates of relative risk of heat effects on occupational injuries.

The objective of this study is to estimate the short-term effects of summer and winter outdoor temperatures and air pollution on the risk of work related injuries, and to identify susceptible groups of workers.

Methods

Study population

We examined all work injuries that occurred between May and September and between November and February in the years 2001- 2010 in three major Italian cities: Milan, Turin and Rome.

Data were extracted from the Italian national workers' compensation authority (INAIL) database, which covers about 85% of Italian workers. For each injury episode that caused absences of three or more days, we gathered socio-demographic characteristics, occupation, and job title, and modalities and causes of the injury. Injuries in subjects younger than 17 years of age were excluded.

Meteorological and air pollution data

Rome, Milan and Turin are large metropolitan areas with different climatic conditions. Milan and Turin are located in Northern Italy and have a cold humid subtropical or mild continental climate, characterized by hot, humid summers with frequent thunderstorms and cold, damp winters often featuring fog in low-lying areas. Rome is located in central Italy 20 km from the Tyrrhenian Sea and has a typical Mediterranean climate with hot, dry summers and mild, wet winters.

Based on previous heat studies conducted in the same cities we chose maximum daily apparent temperature (MAT) [28-30] for the warm season (May-September), [31] and maximum daily temperature (TMAX) for the cold season (November-February) as indicators of temperature.[32] The choice of using two different indicators in the two seasons was driven by statistical reasons; we choose, among the more common indicators used, the one with the best AIC values.

These were measured at the airport station closest to each city. With regards to air pollutants, we used the 24-hr mean daily value of nitrogen dioxide (NO_2) and of particulate matter with an aerodynamic diameter of 10 μm (PM_{10}). Data were extracted from the Regional Environmental Protection Agency (ARPA); values were obtained by averaging monitor-specific daily measurements available from different monitoring stations; we used city-specific daily mean values for all subjects.[33]

Statistical analysis

The analysis was organized in three steps. Because not much is already known about the relationship between work related injuries and temperature and air pollution variations, we first explored the city and season-specific lag structures of each exposure. We used a non-linear distributed lag model (DLNM),[34] allowing a maximum lag structure of 30 days, with the aim of selecting the lags showing the strongest association, using crossbasis centered on the median values of each exposure distribution using a natural cubic spline with df equals 4. As a second step we checked the linearity of the environmental exposure-injury risk relationship, at the lag defined by the previous step, through a Poisson generalized additive model, in each city and season. In both steps models were adjusted for long and seasonal trends using a triple interaction between year, month and day of the week, for holiday days and for influenza epidemics (only in cold season models).

As a third step the effect of environmental exposures on work-injury risk was evaluated using a time stratified case-crossover design separately for each city.[35] For each “case” (the day a work injury occurred) three more days were chosen as controls, matched by day of the week, month and year with the case day, to control for long-term trends, seasonality and day of the week. We estimated odds ratios (OR) and 95% confidence intervals (CI) through a conditional logistic regression model, further adjusted for holidays and influenza epidemics (only in the cold season). Models were exposure, season, and city specific. Lags and shape of the relationship were those defined in the previous two steps. Lagged exposure was computed as the average exposure in the days identified by the lag.

We adjusted one exposure with the others in the model only when their correlation was lower than 0.4.

We tested potential effect modification, of the environmental exposure-injury risk relationship by economic sector (using the Statistical Classification of Economic Activities in the European Community [NACE], Rev. 2 – 2008”), time spent outdoors or indoors (Indoor/Outdoor job activity) and occupational activity, including an interaction term between each variable and the exposure in the model.

Patient and Public Involvement

Patients and or public were not involved in this study

Results

Study Population

We analyzed a total of 468,807 work-related injuries, i.e about 52,000 per month independently by the season (Table 1).

Table 1. Injury distribution by workers' demographic and job characteristics, 2001-2010.

	Warm Season	Cold Season
Total : 468,807	262,804	206,003
Age group, n(%)		
< 30	60,599 (23.0)	48,408 (23.5)
30 - 50	158,086 (60.2)	121,997 (59.2)
>50	44,119 (16.8)	35,598 (17.3)
Gender, n(%)		
Male	165,054 (62.8)	124,671 (60.5)
Female	97,750 (37.2)	81,332 (39.5)
Economic sector, n(%)		
Transport	31,914 (12.1)	24,257 (11.8)
Agro-industry	1,242 (0.5)	969 (0.5)
Fishery	2 (0.0)	2 (0.0)
Mineral extraction	179 (0.1)	140 (0.1)
Electricity gas and water	1,725 (0.7)	1,418 (0.7)
Construction	23,373 (8.9)	16,208 (7.9)
Food, textile and wood industry	6,588 (2.5)	5,264 (2.5)
Electrical, chemical, petrochemical and rubber processing industry	8,445 (3.2)	6,511 (3.2)
Mechanical and metallic industry	10,860 (4.1)	7,413 (3.6)
Business and food service	44,810 (17.0)	34,690 (16.8)
Healthcare system	14,719 (5.6)	11,980 (5.8)
Public services, financial activities	118,947 (45.3)	97,151 (47.2)
Indoor/Outdoor job activity, n(%)		
Indoor	105,215 (40.0)	87,578 (42.5)
Indoor high temperature exposure	7,099 (2.7)	5,669 (2.8)
Indoor/Outdoor	88,231 (33.6)	65,299 (31.7)
Outdoor	23,585 (9.0)	16,442 (8.0)

Missing	38,674 (14.7)	31,015 (15.0)

Meteorological and air pollutants data

Warm season

Rome and Milan showed a common median value of MAT of about 28°C, while Turin showed a median MAT of 26°C. Rome had the higher minimum value for MAT, (**eTable 1**, supplementary material). As for pollution, values were quite similar in the three cities; we observed a moderate correlation between PM_{10} and NO_2 ($\rho \geq 0.5$) in all cities and between MAT and PM_{10} ($\rho=0.4$) in Rome (**eTable 2**, supplementary material).

Cold season

Rome was the warmest city with a median TMAX of 13°C, while Turin and Milan were cooler and had similar median TMAX values of about 8°C. We observed a minimum of -8°C for TMAX in Turin and of -3°C in Milan, while Rome never went below 5°C of TMAX (**eTable 1**, supplementary materials). As for air pollution we observed similar values of NO_2 in the three cities, and higher values of PM_{10} in Turin and Milan. (**eTable 1**, supplementary materials). We observed positive correlations between PM_{10} and NO_2 in Turin ($\rho=0.5$) and Milan ($\rho=0.6$) (**eTable 2**, supplementary material).

Lag structure and shape of the exposure-work injury relationship (step 1 and step2)

Analysis of the lag structure indicated a delayed effect on injury risk of all analysed exposures; during the warm period the greatest effects were observed within the first week after exposure, while in the cold period effects could persist up to 20 days. (**eFigure 1, eFigure 2, eFigure 3**, supplementary material). A summary, for all exposures, of chosen lags and of the shape of relationship (linear/non linear) with WRI risk were reported in Figure 1.

In the warm period the work-related injury/temperature relationship was linear in Rome (**eFigure 4**, supplementary materials) and non-linear in Turin and Milan. In these two cities we estimated ORs comparing city-specific MAT levels chosen in order to maximize the contrast. These points were identified by observing the injury-temperature relationship in eFigure4. In particular, we compared the 90th percentile (33°C) versus the 50th (26°C) in Turin and 90th percentile (34°C) versus the 10th

(21°C) in Milan; results for Rome were reported for the interquartile range (32°C versus 24°C). As for air pollutants, the PM_{10}/WRI relationship was linear in Rome and nonlinear in Turin and Milan (**eFigure 5**, supplementary material), while the NO_2/WRI relationship was linear in Rome and Turin and non-linear in Milan (**eFigure 6**, supplementary material).

In the cold months, the WRI/temperature relationship was non-linear in the three cities (**eFigure 4**, supplementary material). As for the warm period we estimated ORs comparing city-specific TMAX's levels in order to maximize the effect in each city; in particular we compared the 10th percentile (4°C) versus the first percentile (2°C) in Turin, the 25th percentile (6°C) versus the 5th (4°C) in Milan and the 25th percentile (10°C) versus the 5th (8°C) in Rome. Air pollutants–WRI relationship was linear in all the three cities for both PM_{10} and NO_2. In both climatic periods we estimated effects comparing the 95th percentile versus the 25th when the relationship was non linear and for one unit increase when it was linear. Results were always reported for the 95th percentile versus the 25th (**eFigure 5**, **eFigure 6**, supplementary material).

Conditional logistic regression models (step 3)

In the warm season, the univariate analysis showed a positive association between WRI and MAT, PM_{10} and NO_2 in all cities. In the cold season, we observed an inverse association between WRI and TMAX and a positive one between WRI and NO_2 in all cities, and between WRI and PM_{10} only in Rome.

When adjusting temperature for one pollutant at a time in the warm months, the association with WRI resulted to be non-significant, while there was a positive significant effect when adjusting for temperature of both PM_{10} and NO_2 in all cities; in the cold months we observed a significant association of NO_2 with WRI in all cities, and of TMAX and PM_{10} in Rome. We reported only adjusted estimates. (Table 2)

Table 2. Adjusted Odds ratios (ORs) of WRI for temperature and air pollutants levels variations in Turin, Milan and Rome. Period 2001-2010.

Environmental exposures	OR (95% CI)	Comparison

		(percentile)
WARM SEASON *(May-September)* [a]		
Turin		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.02 (0.99, 1.06)	90th vs 50th
PM_{10} (μg/m^3) (Lag* 0-6) [c]	1.09 (1.05, 1.12)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.30 (1.24, 1.37)	95th vs 25th
Milan		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.01 (0.98, 1.04)	90th vs 10th
PM_{10} (μg/m^3) (Lag* 0-7) [c]	1.13 (1.10, 1.16)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.20 (1.16, 1.24)	95th vs 25th
Rome		
Daily maximum apparent temperature (°C) (Lag* 1-7) [b]	1.00 (0.99, 1.02)	75th vs 25th
PM_{10} (μg/m^3) (Lag* 0-7) [c]	1.15 (1.11, 1.18)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-8) [c]	1.22 (1.16, 1.28)	95th vs 25th
COLD SEASON *(November – February)* [d]		
Turin		
Daily maximum temperature (°C) (Lag* 6-21) [b]	1.05 (0.93, 1.18)	1th vs 10th
PM_{10} (μg/m^3) (Lag* 2-12) [e]	0.98 (0.94, 1.02)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-4) [e]	1.11 (1.06, 1.17)	95th vs 25th
Milan		
Daily maximum temperature (°C) (Lag* 6-21) [b]	0.94 (0.92, 0.96)	5th vs 25th
PM_{10} (μg/m^3) (Lag* 0-3) [e]	1.00 (0.98, 1.03)	95th vs 25th
NO_2 (μg/m^3) (Lag* 0-3) [e]	1.09 (1.06, 1.11)	95th vs 25th
Rome		
Daily maximum temperature (°C) (Lag* 0-6) [b]	1.02 (1.00, 1.04)	5th vs 25th
PM_{10} (μg/m^3) (Lag* 5-19) [e]	1.05 (1.03, 1.08)	95th vs 25th
NO_2 (μg/m^3) (Lag* 1-4) [e]	1.04 (1.02, 1.06)	95th vs 25th

[a] Final conditional regression model adjusted by holidays.
[b] Adjusted for NO2
[c] Adjusted for MAT
[d] Final conditional regression model adjusted by influenza epidemics and holidays.
[e] Adjusted for TMAX
* Lags expressed in days.

The effect of NO_2

Exposure to NO_2 showed the highest positive association with the risk of being injured at work in both seasons and in all cities. In the warm season, an increase of NO_2 from the 25th to the 95th percentile was associated with an increase in work injuries ranging between 1.20 (95% CI: 1.16-1.24) in Milan and 1.30 (95% CI: 1.24-1.37) in Turin; in the cold season the effect of NO_2 was lower, ranging between 1.04 (95% CI: 1.02-1.06) in Rome and 1.11 (95% CI: 1.06-1.17) in Turin. (Table 2) No effect modifiers of the NO_2/WRI relationship in either season were found.

The effect of PM_{10}

An increase of PM_{10} from the 25th to the 95th percentile in the warm season was associated with an increase in WRI ranging between 1.09 (95% CI: 1.05-1.12), in Turin, and 1.15 (95% CI: 1.11-1.18), in Rome. During the cold season, we found a significant effect of PM_{10} only in Rome with a 1.05 (95% CI: 1.03-1.08) increase in WRI. (Table 2) No effect modifiers of the PM_{10}/WRI relationship in either season were found.

The effect of temperature

No significant association between temperature and injury risk was observed in the warm season overall, but for workers in the following economic sectors: transportation (Turin 1.00 - *95% CI: 0.89-1.13;* Milan 1.05; *95% CI: 0.96-1.14; Rome 1.04*; *95% CI: 1.00-1.09)*, construction (Turin 1.07 - *95% CI: 0.95-1.21;* Milan 1.07; *95% CI: 0.97-1.17; Rome 1.06*; *95% CI: 1.01-1.12)* and energy industries (Turin 1.56 - *95% CI: 0.95-2.58;* Milan 1.57; *95% CI: 1.03-2.38; Rome 1.00*; *95% CI: 0.85-1.18)* (Figure 2). However the effect was modest.

The association between WRI and temperature or air pollutants by occupational activity was estimated only for those injuries occurred in one of the three economic sectors with a significant association between temperature and WRI, and only in the warm season (Transportation, Construction, and Electricity Gas and Water - Figure 2). In order to have enough statistical power we aggregated into a single category all those occupational activities for which less than 20 injuries were reported in at least one city. Blacksmith, mechanic, installer, motor worker, road worker, warehouse worker, attendant and asphalter were the only activities for which we observed a significant effect of temperature on WRI. The highest effects were observed for road workers (*OR:4.05 - 95% CI:1.20-13.66),* warehouse workers (*OR:4.45 - 95% CI:1.10-18.02)* and attendants (*OR:6.91 - 95% CI:1.42-33.57)*. (Figure 3)

We also observed a significant effect of MAT on those working outdoors in Milan (OR:1.12 - *95% CI: 1.02-1.23)* and Rome (OR:1.07 - *95% CI: 1.01-1.12)*, and among those working both outdoors and indoors only in Rome (OR:1.03 - *95% CI: 1.00-1.06).* No effect was observed among those working only indoors (Figure 4).

In the cold season, a decrease of TMAX from 4°C to 2°C was associated with a weak and not significant increase in WRI (OR: 1.02; 95% CI: 1.00-1.04) in Rome (Table 2) while in Turin and Milan no effect was observed. No effect modifiers of TMAX-WRI in the cold season were found.

Discussion

This is the first study conducted in Italy to analyze the independent effects of temperature (hot and cold) and air pollutants on the risk of work-related injuries. The strongest effects on WRI risk was due to exposure to NO_2 in the warm season, with a WRI risk up to 1.3 times higher when NO_2 levels increased from the 25th to 95th percentile of its city-specific distribution.

In general we observed a significant association between exposure to NO_2 and WRI in both seasons and in all cities; and between PM_{10} and WRI only in Rome during the cold season and in all the three cities during summer. Temperature showed a significant effect only in specific occupational activities during the warm season (May to September).

The relationship between NO_2 and the occurrence of work related injuries had a similar shape in the three cities in both periods (**eFigure 6**, supplementary material). As expected, NO_2 values were lower in the warm than in the cold season, with median values in the three cities of about 50 µg/m^3 and 73 µg/m^3 respectively (eTable 1). Despite this, there was a stronger association between NO_2 and WRI in the warm than in the cold season, although levels of NO_2 in the cold season are always higher. It is also noticeable that the effect of NO_2 remained constant regardless of economic sector or occupational activity.

The relationship between PM_{10} and the occurrence of work related injuries had a non linear shape in Turin and Milan, while was linear in Rome in the warm season; during winter, instead, the shape was similar in the three cities (**eFigure 5**, supplementary material). PM_{10} levels showed a similar trend as

NO_2, with lower levels in the warmer months and higher levels and a low day by day variability in the cold period. Only in Rome, the southern of the three cities, PM_{10} showed lower and more variable levels in the cold period. (**eTable 1**, supplementary material); and it is interesting to observe that an increase of PM_{10} is associated to an increase in WRI in this season only in Rome. In the warm months the effect of PM_{10} is consistent in the three cities, but lower then that of NO2. On days in which PM_{10} levels reach the 95th percentile of the city specific distribution the risk of WRI is circa 10% higher than on days when PM_{10} levels are around their 25th percentile.

The differences observed in the shape of the pollutant-WRI risk among cities could be explained by the different geographical and climatic characteristics and also by sources of air pollution; for example in Rome there are additional sources on particulate matters levels, above all Saharan dust storms [36].

Mounting experimental evidence suggests in addition to the well-known short-term effects on various health outcomes [23, 37-38], such as cardiopulmonary system, the brain may be a target of air pollution. Specific mental and neurological disorders, such as depression and headache, as well as suicide have all been linked to ambient air pollution.[39,40] Moreover evidence on acute neuropsychological effect has been studied only very recently on humans by Sunyer et al.,2017, [21] showing a short-term association between air pollutants and fluctuations in attention in children. These effects could probably arise through the same mechanism as the long-term association, since a recent review [22] showed as potential mechanisms oxidative stress/inflammation, altered levels of dopamine and/or glutamate and changes in synaptic plasticity/structure based on consistent evidence from animal studies. Inhaled concentrated ambient particulate matter is deposited in pulmonary alveolar regions of lung from which it can pass to the blood circulation and thus impact other organs and produce neuroendocrine and neuropathological alterations.[41] Another gateway to the brain involve translocation of pollution across the olfactory epithelium in the nasal cavity. [22] In our study the lag of PM_{10} and NO_2 effects was short, two or three days;[42] so it is reasonable to think that these exposures might explain the association between pollution and work related injuries. Some previous studies have analyzed health-related outcomes in specific categories of workers, particularly those exposed to urban stressors, such as street vendors and policemen, and they showed some effects on cardiovascular diseases, pregnancy outcomes, and respiratory diseases.[43-47,20] One study measured a negative economic impact of exposure to air pollutants in agriculture workers, finding lower productivity on more polluted days.[20] Finally, a recent study [43] tried to measure the association between occupational exposure to ozone and respiratory diseases, with no conclusive results. It could be considered that above mentioned mechanisms may differ between seasons; during the warm season, part of the observed effect of pollutants may be attributable to the synergistic effect between temperature and air quality as previously suggested in the general population studies [48]. One mechanism involve the higher frequency of air pollution peaks occurring during stagnation events common in summer season. Moreover, during the hottest months the activation of thermoregulatory mechanisms such as the increase in ventilation rate could increase the intake of air pollutants into the airways.

As for heat, our study showed an increase of injuries only among bricklayers, blacksmiths, mechanics, installers and asphalters working in transportation, construction and energy economic sectors , and in the more generic group of those working outdoor or performing both outdoor and indoor tasks, but not among those who work only indoors. These results are consistent with previous studies.[49,50, 31]

It is interesting that the unadjusted OR of MAT on WRI during the warm season ranged from 1.03 in Rome (75° vs 25° percentile, range=8°C) to 1.06 in Turin (90° vs 50° percentile, range=7°C), but these effects lowered to 1.01 and became not significant when adjusting for air pollution. The observed confounding of temperature by pollution should be considered when comparing our results to unadjusted estimates of temperature-WRI associations from other published studies.

Two previous studies conducted in Italy [51] and in Australia [49] found an inverse U-shaped relationship between high temperatures and WRI in summer, with maximum risk on warm days but not on extremely hot days. The relationship observed in Turin and Milan (eFigure4) also suggest a similar trend, even if quite weak. Also, the values of MAT in correspondence of which the highest rates of injuries were observed were 33°C-34°C, while they remained stable or decreased afterwards. In Rome, which experiences warmer summer conditions than Milan and Turin, we found a linear relationship consistent with what was observed in two recent studies conducted in Melbourne and in Quebec. [50,12] Different population characteristics as well as temperature distributions might influence these differences between cities. Furthermore, it has to be considered that the trend in the effects observed in Milan and Turin might be biased by the lower statistical power in the highest extremes of the temperature distribution, due to the fewer days observed with those temperature levels. This is not the case in Rome where temperatures even above 34°C are adequately represented. Ambient heat might increase metabolic heat that is normally produced in activities requiring physical exertion; accordingly we have observed an effect of heat in more physically demanding economic sectors and occupational activities. We categorized workers according to three different criteria as suggested in a previous study:[12] economic sector, occupational activity and outdoor or indoor location. This classification allowed us to measure both the risk associated with physical demands (economic sector and occupational activity) and the gradient of exposure to outdoor heat. Our results showed higher susceptibility among those working outdoors and no effects on those working only indoors, confirming that those working outdoors are more susceptible to pollution and temperatures exposure. However, when analysing single occupational activities, we found that among the most susceptible to heat there were some (mechanics, warehouse workers and attendants) who spend more time indoor than outdoor but still require high physical exertion. Strenuous activity, and use of heavy impermeable personal protective clothing might increase metabolic heat and increase the risk of injuries. This might suggest that the level of physical strength required by the occupation might be an important effect modifier to be taken into account for heat-related risk, independent of work location.[12]

Our study also examine the effect of temperature and air pollutants in the cold season. As for pollution, the effect is lower than in summer; for temperature, we did not observe an effect of cold.

A previous study conducted in Tuscany, in the center of Italy, found significant cold effects on outdoor occupational injuries especially among agricoltures and in drivers of vehicles other than cars [52].

An important strength of this study is that we estimated the independent effects of temperature and air pollution, controlling one for the other in the model. Also, we used a very large dataset that was not derived from self-reported data. However, our study presents some limits. The study population was drawn from the Italian public insurance system database that covers all work-related injuries due to violent causes that leads to death, permanent disability or temporary total disability lasting at least three days, and all occupational diseases. It is remarkable to consider that workers covered by the public insurance system for injuries and occupational diseases make up approximately 80-85% of the whole workforce in Italy. However, daily injury claims may be underestimated because of under-reporting of workers' compensation claims and due to incomplete coverage of the public insurance system lead by INAIL. Some occupational activities, such as firefighters and the armed forces, benefit from a specific welfare system in Italy and are not included in the analyzed dataset. The distribution of daily injury claims by economic sector varies greatly and the relatively small numbers in some sectors dictates a cautious interpretation of results for less represented subgroups.

All exposure measures used were daily averages deriving from fixed points of measurement in the city, implying each worker was attributed the same level of exposure independently of his location in the city at the moment of injury, thus having a potential bias in exposure due to different temperatures and pollutants within the city on a given day. However, the error associated with this generalization in exposure is considered to be low.[53] Finally collinearity among NO_2 and PM_{10} didn't allow to adjust one pollutant for the other, so that the estimate of pollutant effect might be confounded by concomitant exposure to the other one. This limit is proper of almost all air pollution studies.

Conclusions

Our results show that , after removing the confounding effect of co-exposure to air pollution, the exposure to high temperature represents a risk only among workers who have heavier work loads and among those who spend most of their time outdoors. Our results also suggest that exposure to air pollution, especially NO_2, seems also to increase the risk of work related injuries with a stronger effect in the warm months. These results suggest the need to further look into this association, to confirm our findings and to better understand the underlying mechanisms. In conclusion, our results confirms that in Italy, which is a Mediterranean country with a generally mild climate, ambient exposures represent a hazard for work related injuries. These results contribute to the increasing knowledge about the association between temperature and work related injuries, and add new evidence about the potential effects of pollutants that have not yet been studied in Italy except on very specific subgroups.

Identifying specific subgroups of workers as the most susceptible to these specific exposures is crucial information for public health organizations in order to properly target prevention plans.

Abbreviations

WRI, work related injuries;

PM_{10}, particulate matter with an aerodynamic diameter of 10 μm or less;

NO_2, nitrogen dioxide;

MAT, maximum apparent temperature;

TMAX, maximum temperature;

DLNM, non-linear distributed lag model;

OR, odd ratio;

CI, confidence interval.

Declarations

Acknowledgments

Authors aknowledge Dr. Simona Vecchi for her suggestions in the final revision of the manuscript; Giuseppe Campo and Fabio Cosimi (INAIL, Rome) for supporting in the retrieving and interpretation of injuries data and Julie Sawitzke for her carful editing and English review.

Funding

The study was carried out within "Cambiamenti climatici, inquinamento atmosferico e pollini: Modello integrato di monitoraggio dell'esposizione ambientale, allerta, sorveglianza rapida sanitaria e promozione di misure di prevenzione per ridurre l'impatto sulla salute"funded by CCM – Ministero della Salute.

Availability of data and materials

The data that support the findings of this study are available from *Occupational and Environmental Medicine, Epidemiology and Hygiene Department, Italian Workers' Compensation Authority (INAIL), Rome, Italy* but restrictions apply to the availability of these data, which were used within the collaboration for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request. and with permission of INAIL.

Authors' contributions

PS conceptualized and designed the study, drafted the manuscript. FA carried out the statistical analyses, reviewed and revised the manuscript. AM and MB contributed to the draft, critically reviewed the manuscript. MD critically reviewed the manuscript. PM collaborated to conceptualize and to desig the study, reviewed and revised the manuscript. All authors read and approved the final manuscript as submitted.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests to disclose.

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Figures:

Figure 1. Graphical summary of lags and shapes of exposures/WRI relationship (linear/non linear) by season and city.

Figure 2. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase*, by economic sectors, during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

Figure 3. Odds Ratios of WRI, adjusted for NO_2, for MAT (lag1-7) increase* by occupational activities, in *Transportation, Construction, Electricity gas and water* industries, during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT

Figure 4. Odds Ratios of WRI for MAT*, NO_2§ and PM_{10}§ increases by "Indoor/Outdoor job activity" during warm season (May-September) in Turin, Milan and Rome.

* *Turin: 90° vs 50° percentile of MAT*
Milan: 90° vs 10° percentile of MAT
Rome: 75° vs 25° percentile of MAT
§ *95° vs 25° percentile of the distribution of the both air pollutants in the three cities*

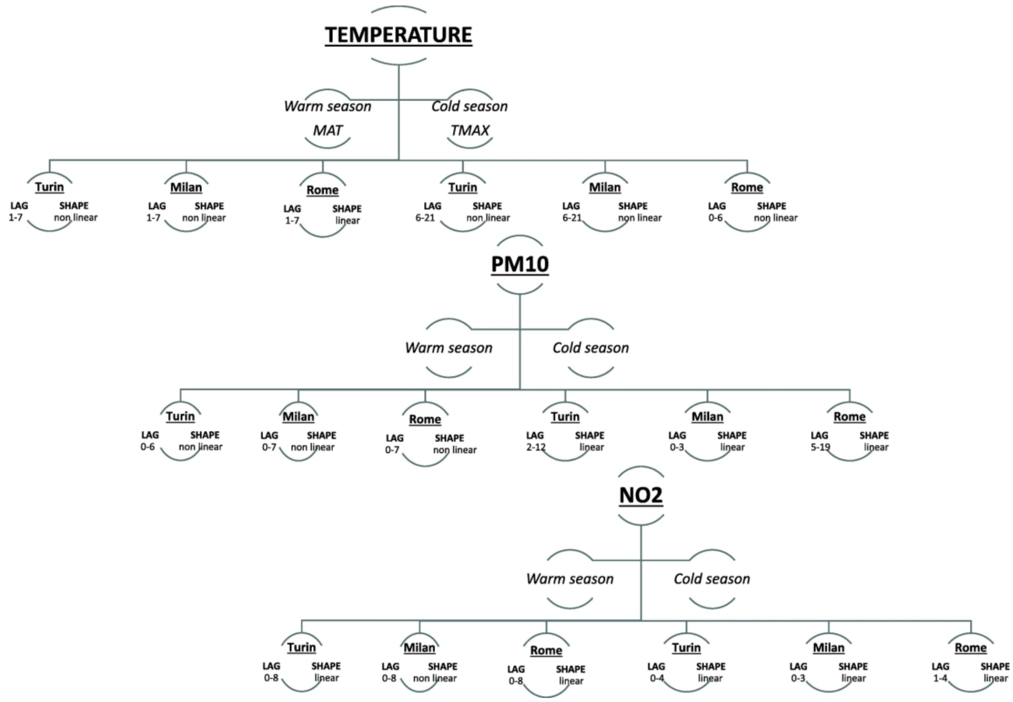

Figure 1

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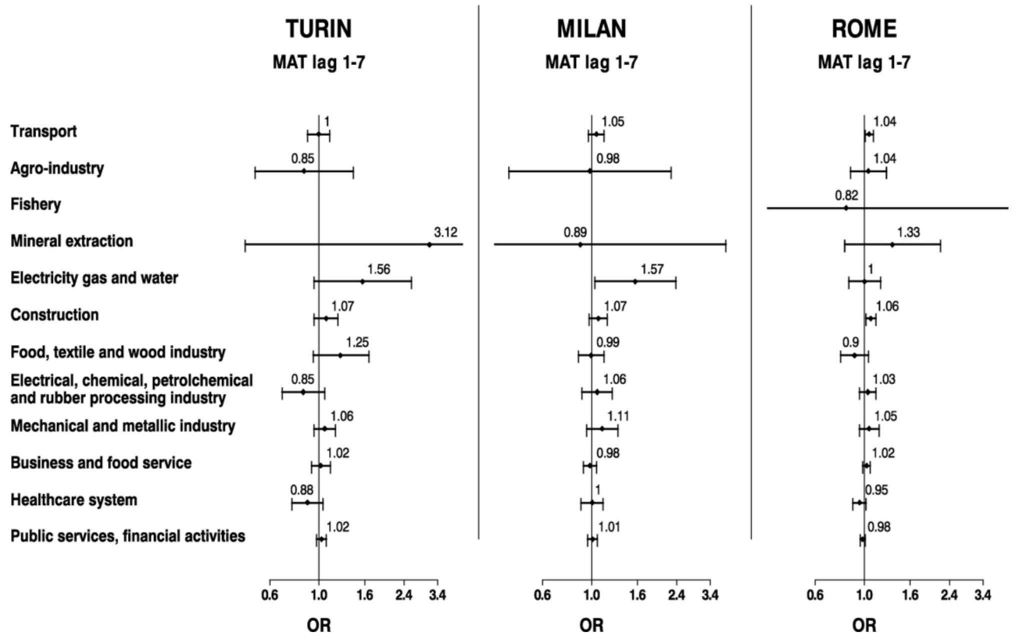

Figure 2

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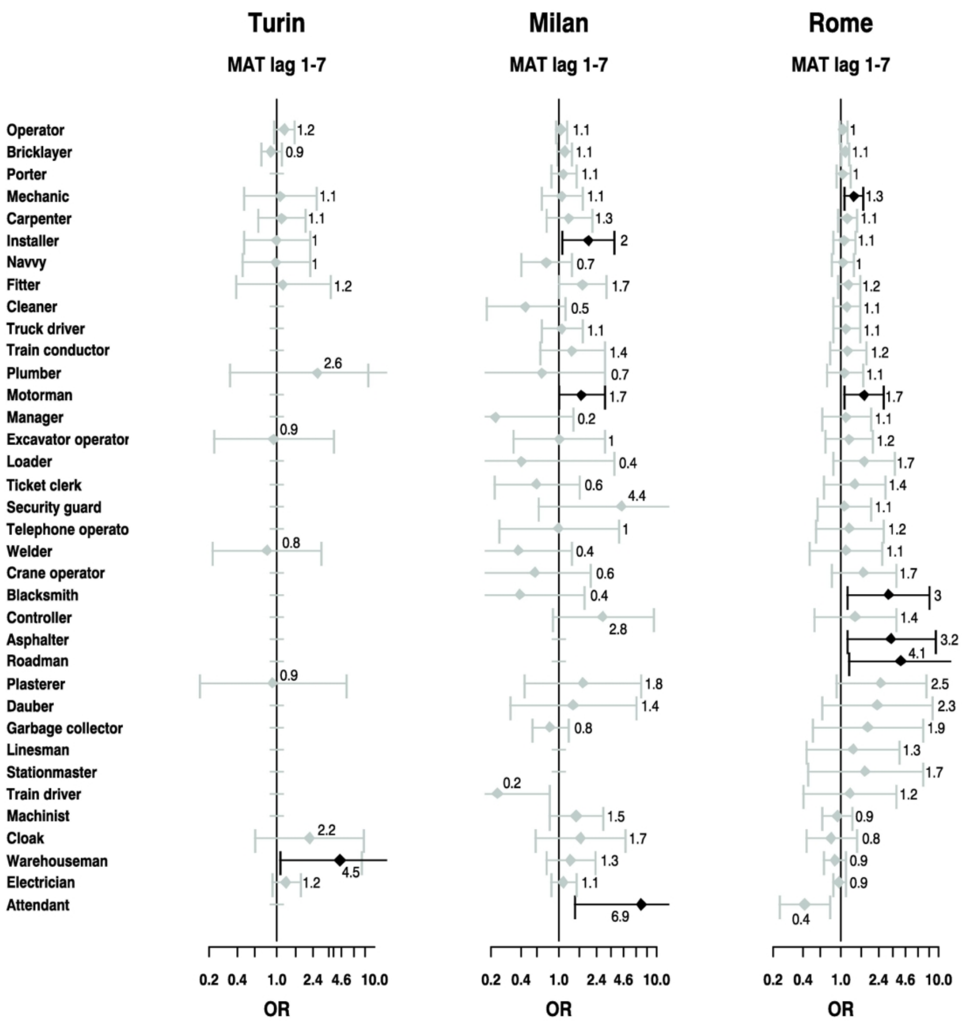

Figure 3

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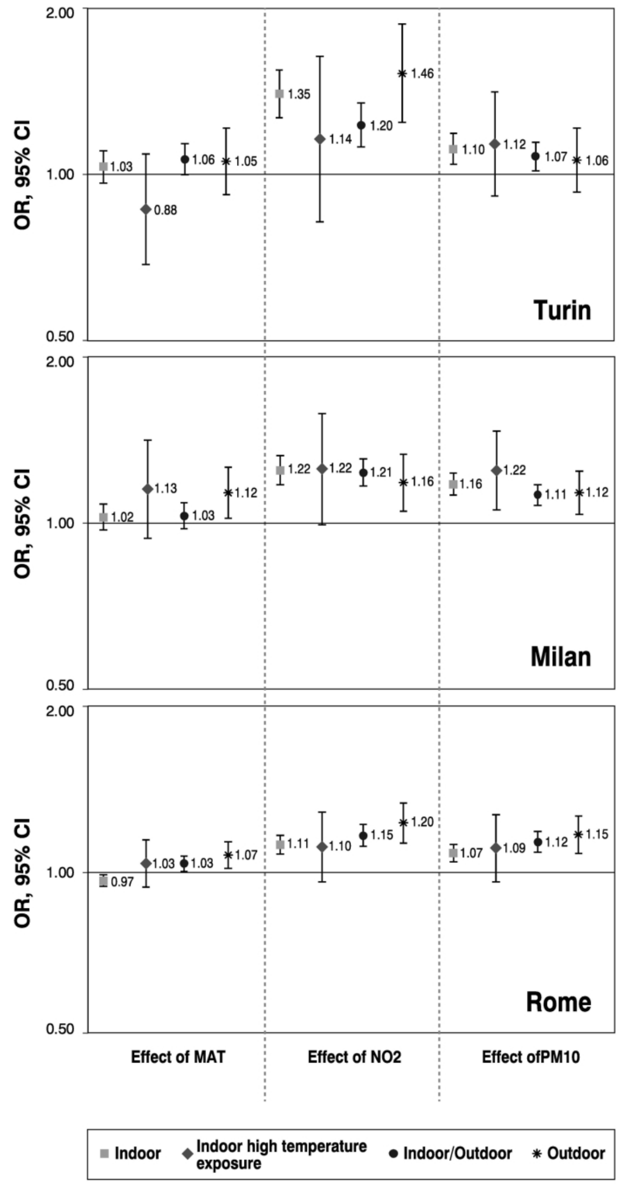

Figure 4

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eTable 1. Temperature and pollutants distribution in Turin, Milan and Rome by seasonal period, 2001–2010.

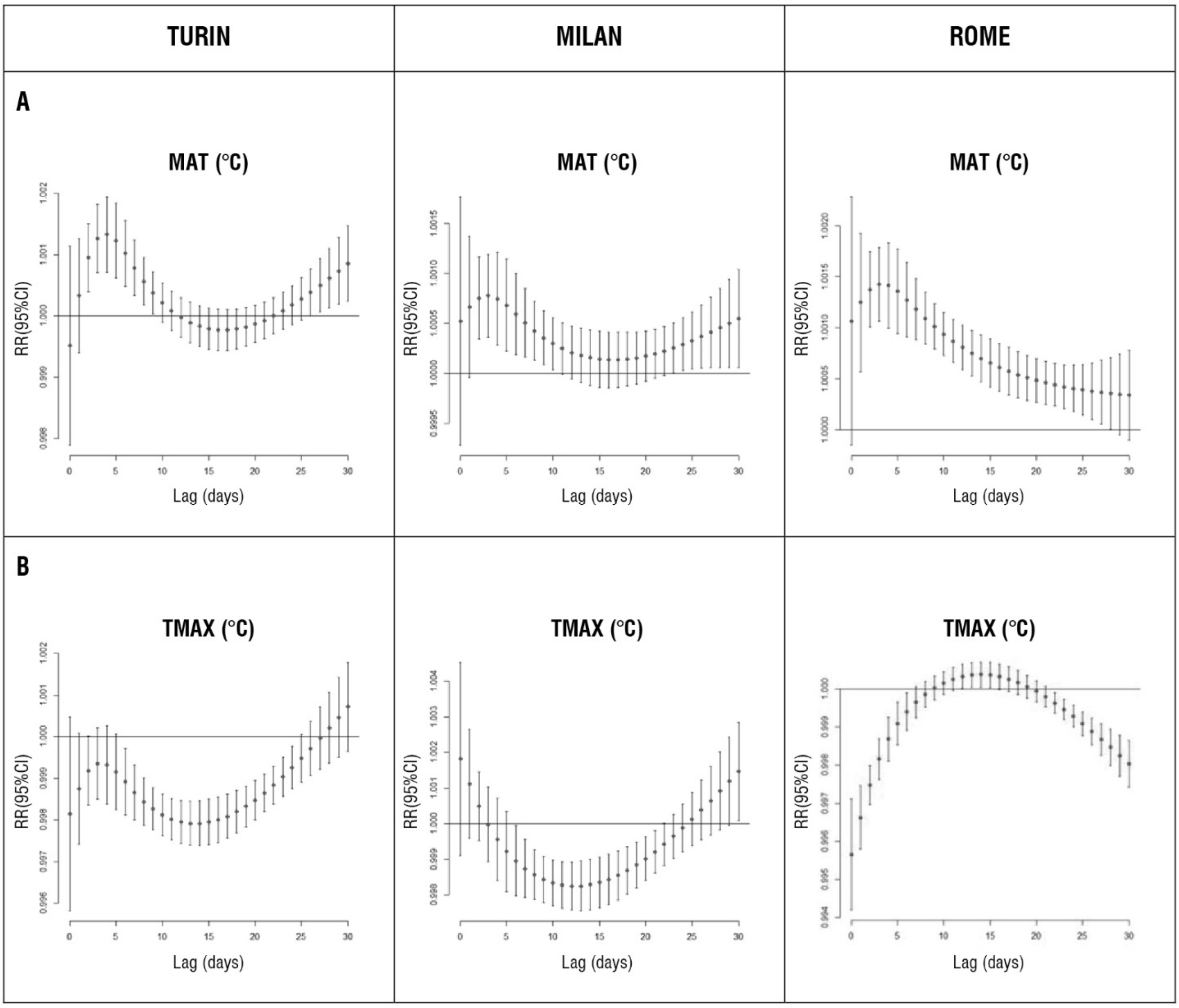
Exposure	Min	25° pctl	50° pctl	75° pctl	Max
WARM SEASON (May - September)					
Turin					
Daily maximum apparent temperature (°C)	9.0	22.3	26.3	30.1	39.7
PM_{10} (μg/m^3)	1.0	20.7	28.0	36.5	89.5
NO_2 (μg/m^3)	12.7	36.8	47.2	59.6	135.1
Milan					
Daily maximum apparent temperature (°C)	6.7	23.9	28.3	32.6	44.0
PM_{10} (μg/m^3)	4.9	22.5	29.6	38.5	87.4
NO_2 (μg/m^3)	11.2	33.9	43.4	53.8	128.1
Rome					
Daily maximum apparent temperature (°C)	12.4	24.4	28.3	32.2	39.7
PM_{10} (μg/m^3)	7.3	26.3	32.1	39.6	106.0
NO_2 (μg/m^3)	11.9	41.9	52.3	62.7	110.1
COLD SEASON (November – February)					
Turin					
Daily maximum temperature (°C)	-7.6	4.7	7.7	10.9	24.9
PM_{10} (μg/m^3)	8.0	50.5	75.0	102.0	242.0
NO_2 (μg/m^3)	19.9	64.9	79.0	92.9	197.9
Milan					
Daily maximum temperature (°C)	-3.2	5.3	8.3	11.3	21.6
PM_{10} (μg/m^3)	9.3	44.3	67.3	93.2	314.6
NO_2 (μg/m^3)	29.6	60.2	72.3	87.2	202.1
Rome					
Daily maximum temperature (°C)	5.5	10.3	12.6	14.5	23.2
PM_{10} (μg/m^3)	10.7	27.4	39.4	53.9	141.6
NO_2 (μg/m^3)	23.9	58.4	68.1	78.2	117.3

eTable 2. Pearson correlation coefficients between daily temperature and pollutants in both seasons for the three cities.

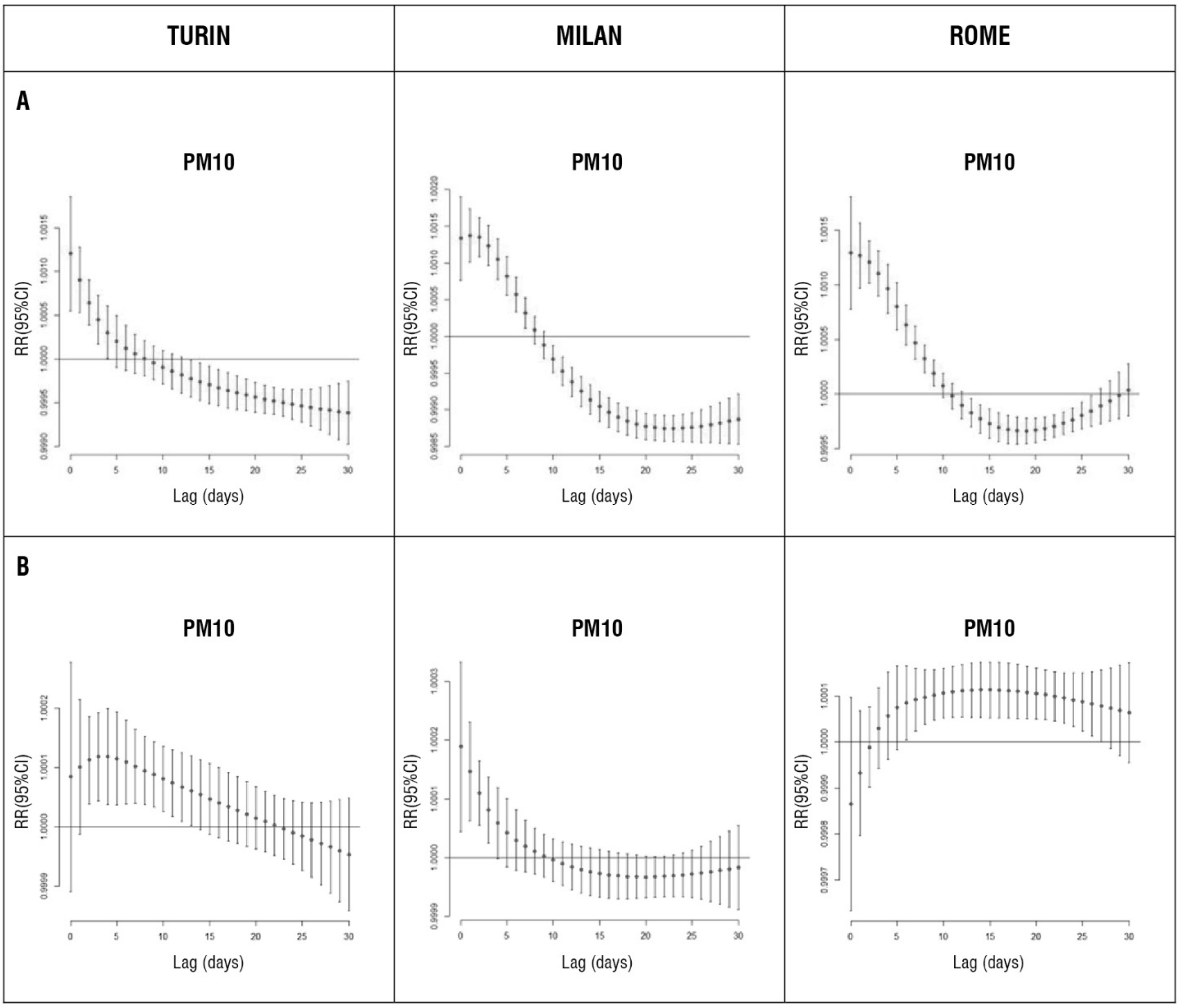
WARM SEASON				COLD SEASON			
TURIN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-6		TMAX lag 6-21	NO2 lag 0-4	PM10 lag 2-12
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.12*	1		NO2 lag 0-4	-0.42*	1	
PM10 lag 0-6	-0.01*	0.61*	1	PM10 lag 2-12	-0.20*	0.51*	1
MILAN							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 6-21	NO2 lag 0-3	PM10 lag 0-3
MAT lag 1-7	1			TMAX lag 6-21	1		
NO2 lag 0-8	-0.22*	1		NO2 lag 0-3	-0.36*	1	
PM10 lag 0-7	0.28*	0.56*	1	PM10 lag 0-3	-0.29*	0.77*	1
ROME							
	MAT lag 1-7	NO2 lag 0-8	PM10 lag 0-7		TMAX lag 0-6	NO2 lag 1-4	PM10 lag 5-19
MAT lag 1-7	1			TMAX lag 0-6	1		
NO2 lag 0-8	-0.08*	1		NO2 lag 1-4	-0.05	1	
PM10 lag 0-7	0.40*	0.49*	1	PM10 lag 5-19	-0.01	0.19*	1

* p-value < 0,05

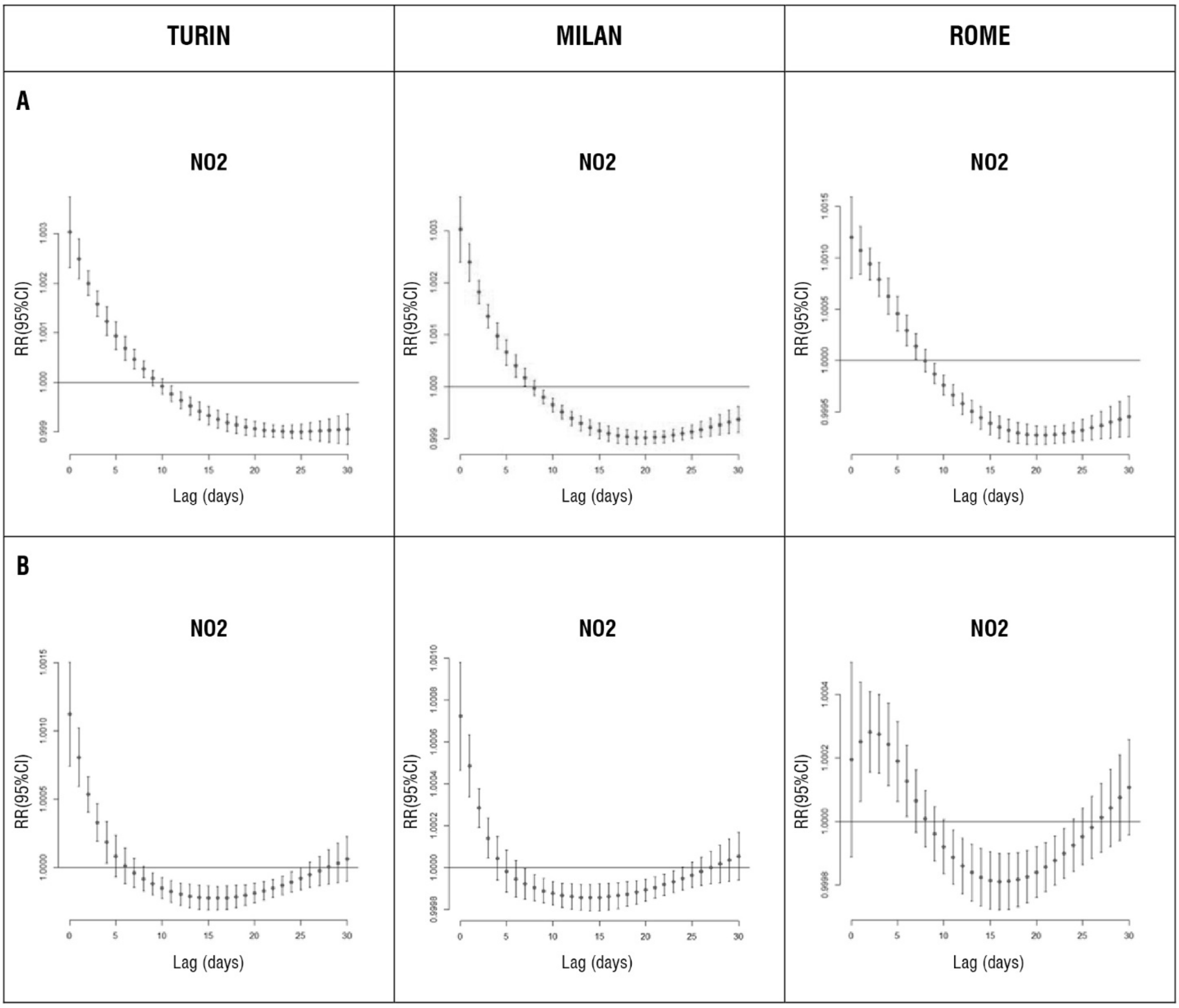
eFigure 1. Lag structure of Relative Risks (RR) of injury for 1 °C increase in temperature in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



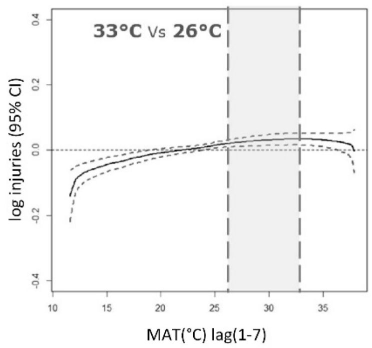
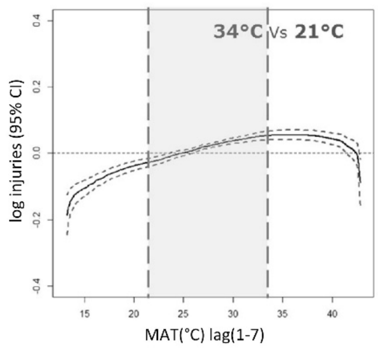
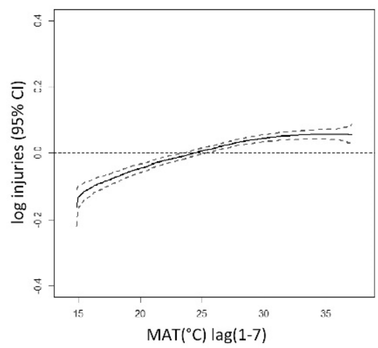
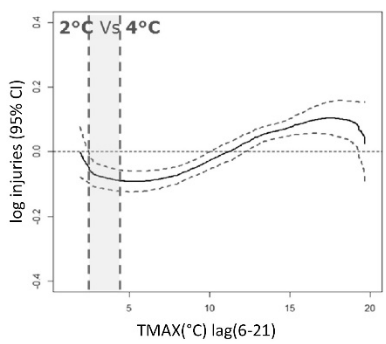
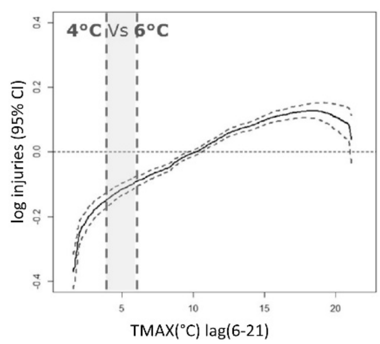
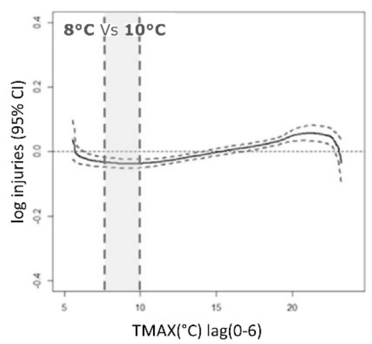
eFigure 2. Lag structure of Relative Risks (RR) of injury for 1 µg/m3 increase in PM_{10} in the three cities obtained by a non-linear distributed lag models, warm season (A) and cold season (B)



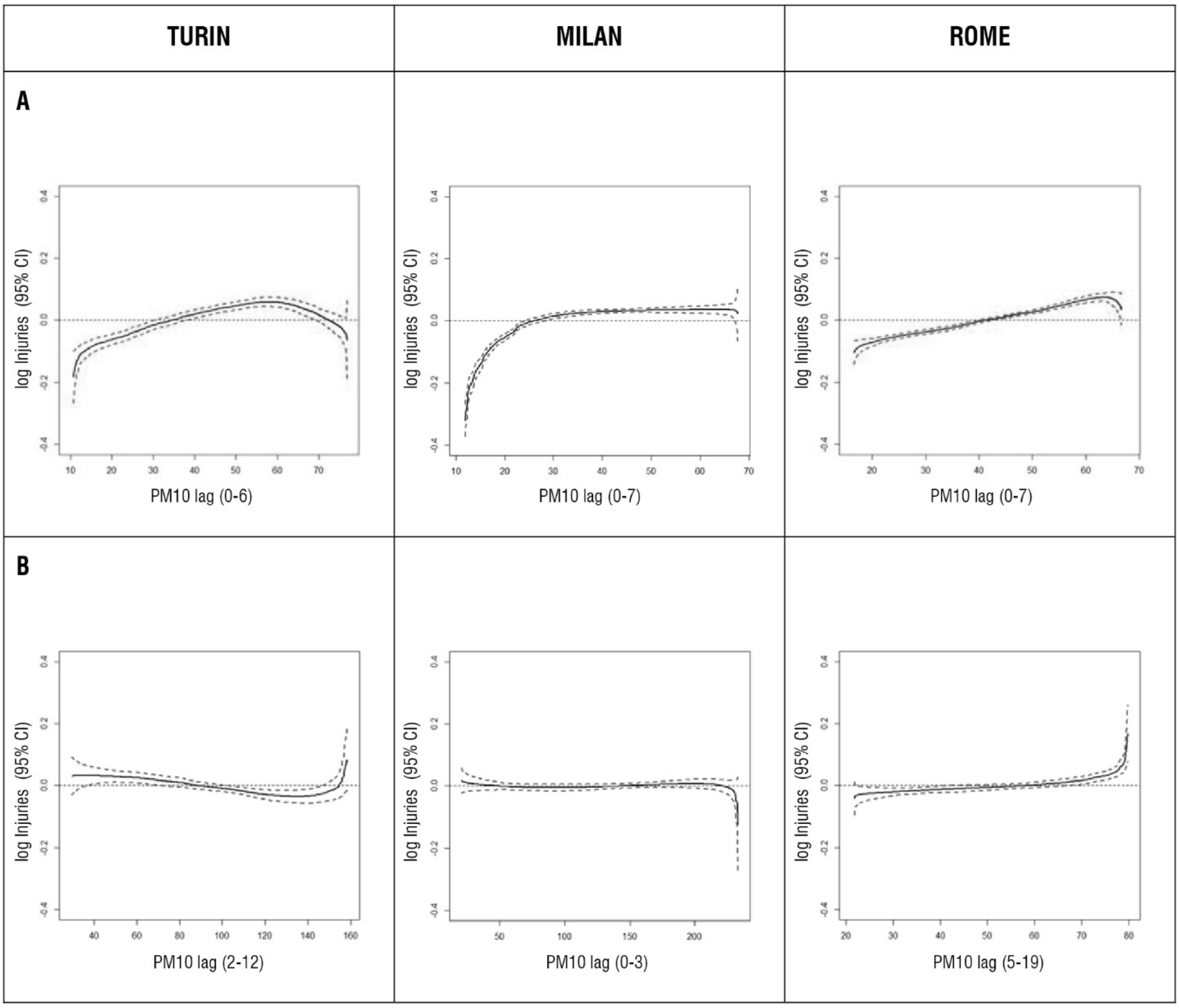
eFigure 3. Lag structure of Relative Risks (RR) of injury for 1 μg/m3 increase in NO_2 in the three cities obtained by distributed lag models, warm season (A) and cold season (B)



eFigure 4. The injury-temperature relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models

	Turin	Milan	Rome
A			
B			

eFigure 5. The injury–PM_{10} relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models



eFigure 6. The injury–NO_2 relationship in Turin, Milan and Rome in warm season (A) and cold season (B), estimated by a Poisson generalized additive models