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Heat and cold related-mortality in 18 French cities

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ABSTRACT

Objectives: Understanding the dynamics of the temperature-mortality relationship is an asset to support public health interventions. We investigated the lag structure of the mortality response to cold and warm temperatures in 18 French cities between 2000 and 2010.
Methods: A distributed lag non-linear generalized model using a quasi-Poisson distribution and controlling for classical confounding factors was built in each city. A fitted meta-analytical model combined the city-specific models to derive the best linear unbiased prediction of the association, and a meta-regression explored the influence of background characteristics of the cities. The fraction of mortality attributable to cold and heat was estimated with reference to the minimum mortality temperature.
Results: Between 2000 and 2010, 3.9% [CI 95% 3.2:4.6] of the total mortality was attributed to cold, and 1.2% [1.1:1.2] to heat. The immediate increase in mortality following high temperatures was partly compensated by a harvesting effect when temperatures were below the 99.2 percentiles of the mean temperature distributions.
Discussion: Cold represents a significant public health burden, mostly driven by moderate temperatures (between percentiles 2.5 and 25). The population is better adapted to warm temperatures, up to a certain intensity when heat becomes an acute environmental health emergency (above percentile 99). The rapid increase in mortality risk at very high temperatures percentiles calls for an active adaptation in a context of climate change.

1. Introduction

The Intergovernmental panel on climate change states that warming of the Earth is unequivocal, and that it is very likely that the numbers of warm days and nights have increased (while cold days and nights have decreased). Heat waves frequency is already likely to have increased in large parts of Europe and other world regions (Stocker et al., 2013). In this changing climate, there is a growing need to understand how ambient temperature affects human health and how its impacts can be reduced.

The physiological consequences of exposure to heat and cold, and the mechanisms involved in the thermoregulation systems are well documented (Hanna and Tait, 2015). The epidemiological literature also provides evidence on the short-term relationships between temperature, temperature variability, temperature extremes and health indicators (mortality, morbidity, for all-causes and for specific causes) (Smith et al., 2013). Worldwide, the shapes of the temperature-all-causes mortality relationships are consistent (Smith et al., 2013; Gasparrini et al., 2015; Anderson and Bell, 2009; Analitis et al., 2008; Baccini et al., 2008; Wang et al., 2017; Ma et al., 2015), and compatible with the physiological knowledge. They underline a moderate delayed effect of cold, sustained over several weeks, and an acute, immediate effect of heat. Recent studies found that between 3% and 11% of the mortality could be attributed to non-optimal temperatures, mostly to cold, mild temperatures, which are still more frequent than warm temperatures (Gasparrini et al., 2015).

The global consistency of the shapes of the temperature-mortality relationships does not exclude local specificities, calling for prevention strategies tailored to the local climate conditions (Ma et al., 2015). In France, policies to prevent the health impacts of temperatures have focused on heat waves and cold spells, in response to major events.

The 2003 August heat wave was the worst climate hazard ever recorded in terms of intensity and duration in several French regions. It caused around 15,000 excess deaths between the 1st and the 15th August 2003 (Fouillet et al., 2006). Its consequences have deeply influenced the response to temperature-related risks in France. Results of epidemiological studies following the 2003 heat wave in France (Fouillet et al., 2008; Le Tertre et al., 2006; Ledrans et al., 2004; Pascal et al., 2012a; Laaidi et al., 2012) have rapidly supported the implementation of a national heat wave prevention plan in 2004 (Haut Conseil de Santé Publique, 2014). This plan is based on three complementary pillars; 1) raising awareness among the general population

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and among professionals through communication and training, 2) reducing heat exposure for the most vulnerable (e.g. by developing cool rooms in nursing homes) and 3) taking immediate preventive actions during the most extreme episodes. Those episodes are anticipated by a heat wave warning system based on weather forecast (Pascal et al., 2006; Pascal et al., 2013). The near-real time health impacts are monitored through a syndromic surveillance system (Pascal et al., 2012b; Antics et al., 2012). Between 2004 and 2014, 196 heat waves corresponding to heat warnings (at the departmental scale) were observed in France, totaling around 1500 excess deaths (Wagner et al., 2018). In 2015, several short but very intense heat waves were associated with about 1700 excess deaths. Around 400 excess deaths were observed during heat waves in 2016, and again 480 excess deaths in 2017 (Pascal et al., 2018).

By contrast, cold spells were never associated with a large mortality impact, but cold has been identified as one of the factors contributing to excess winter mortality (Phu Pin et al., 2012). The relevance and feasibility of developing a cold warning system, similar to the heat warning system, had been investigated in two pilot cities, concluding that long-term interventions (e.g. housing improvement) were likely to be the most efficient to prevent the adverse effects of cold (Laaidi et al., 2013). Cold warnings are restricted to very rare situations.

While several studies have investigated the mortality impacts of temperature in France during extreme events (Fouillet et al., 2006; Fouillet et al., 2008; Le Tertre et al., 2006; Pascal et al., 2012a; Phu Pin et al., 2012; Laaidi et al., 2013; Vandentorren et al., 2004), few studies have documented the temperature-mortality relationship in France and the impacts of milder temperatures. Studies considering the city of Paris reported a J shaped relation (Analitis et al., 2008; Baccini et al., 2008; De Donato et al., 2015). Todd et al. analyzed the temperature-mortality for 224 areas in France, and also reported a U or J shaped-relationship, with a minimum mortality temperature (MMT) positively correlated with the mean summer temperature (Todd and Valleron, 1968–2009). However, those analyses did not consider the lag structure of the relationship, and a comparative assessment of heat and cold impacts was still missing. To fill this gap, we investigated the temperature-mortality relationship in 18 continental French cities between 2000 and 2010, with a specific focus on the variations of the lag-structure of the response. We explored if the results supported the current prevention focus on extreme events. We also investigated possible changes in the mortality response after 2003.

2. Methods

2.1. Period and study areas

Participating cities were selected to capture the diversity of climates and urban environments in France, with the constraint of hosting > 100,000 inhabitants to ensure sufficient statistical power (Fig. 1). In each city, the study area was defined taking into account the continuity of the urban tissue, commuting, and homogeneity toward air quality and climate conditions.

The study covered 2000–2010, i.e. a period when no heat prevention was available (2000 − 2003), and a period when the national heat wave prevention plan was activated (2004–2010).

2.2. Data

For each city, daily total mortality was obtained for the 2000–2010 period from the French National Institute of Health and Medical Research (CepiDC). Total population, population aged 75 and over, population density, and the fraction of households with no taxable incomes were obtained from the National Institute of Statistics and Economic Studies (Insee), for 1999 and 2010.

A preliminary pilot study showed that several temperature indicators could be used to model the mortality with similar performances, and that absolute nor relative humidity did not modify the temperature-mortality response (Schaeffer et al., 2016). Daily mean temperature was chosen as the exposure indicator in the following.

Daily mean temperatures were provided by the French national meteorological service Météo-France for a reference station per city. Airport stations were used for 15 cities, and city center stations for 3 cities (Supplementary material - Table S1).

Daily ozone and PM_{10} concentrations (8 h-max for ozone and daily mean for PM_{10}) were collected from the local air quality monitoring networks. Exposure to ozone was computed as the average of the 8 h-daily maximum ozone concentrations across all urban and peri-urban air quality monitoring stations in each study area, while exposure to PM_{10} was computed as the daily average of daily PM_{10} concentrations across all urban monitoring stations.

2.3. Statistical modeling

In each city, the temperature-mortality relationship was investigated with a distributed lag non-linear generalized model (DLNMs), using a quasi-Poisson distribution adapted to account for mortality over-dispersion. The model controlled for the day of the week, holidays, long-term trend, seasonality and air pollutants. Long-term trend and seasonality were approached with a natural spline using 8 degrees of freedom (DF) per year for the largest cities, Paris, Marseille, Lille and Lyon, and 3 degrees of freedom for the other cities. Using 8 DF/year is a common approach in the literature, while 3 DF/year are also frequently applied for weak seasonal trends (Samoli et al., 2013; Katsouyanni et al., 2009). Alternative models were performed using 3, 5 or 8 DF/year in all cities.

PM_{10} and ozone concentrations averaged across lag 0–1 were introduced in the models as linear terms. Alternative models did not controlled for PM_{10} and ozone.

The use of DLNMs allows describing the exposure-lag-response association, i.e. taking into account the non-linear temperature-mortality relationship and its delayed effects over time (Gasparrini et al., 2010). The association in the dimension of temperatures was modeled through a quadratic B-spline with three internal nodes located at the 1st, 60th and 99th percentiles of the temperature distribution. The choice of these nodes was based on the Akaike criteria. The association in the dimension of lags was modeled with a natural spline with two internal nodes placed at equally spaced values in the logscale, to allow for more flexibility in the first lags were more variability is expected. Individual lags were investigated up to 21 days.

For each city, the non-linear association was centered on the 50th percentile of the daily mean temperature distribution of the city, and the risk estimates were expressed for temperature percentiles, relatively to this 50th percentile. The estimated city-specific overall cumulative exposure-responses were combined using a multivariate meta-analytical model (Gasparrini et al., 2012). Relative risks (RR) are presented cumulated over 0–21 days, and over 0–3 days.

A meta-regression explored possible causes of heterogeneity across cities, searching for the influence of climate, longitude, latitude, altitude, population density, percentage of population aged 75 and over and fraction of households with no taxable income. Effects were tested using a Wald test, and the residual heterogeneity, representing the proportion of total variation due to differences between cities, was measured with the I^2 (Higgins and Thompson, 2002).

A fitted meta-analytical model was used to derive the best linear unbiased prediction of the overall cumulative exposure-response association in each city (Gasparrini et al., 2012; Le Tertre et al., 2005). Using the method developed by Gasparinni et al. (Gasparrini et al., 2015; Gasparrini and Leone, 2014), these best linear unbiased predictions were used to assess the minimum mortality temperature (MMT) in each city, i.e. the temperature corresponding to the lowest predicted mortality. We calculated the number of deaths attributable to cold as the sum of mortality predicted for each day with a temperature lower