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Excess male mortality and age-specific mortality trajectories under different mortality conditions: A lesson from the heat wave of summer 2003

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ABSTRACT

Introduction: Our objective was to study the impact of an identical additional stress on male and female mortality with a quasi-experimental study design, using natural variations in summer mortality, including the massive heat wave that struck Europe in 2003.

Material and Methods: The summer daily mortality rates of the population aged 65 and over living in 16 European countries were computed by single age from 1998 to 2003. Using the method of Tukey, we established five categories summarizing the summer daily conditions of mortality (exceptionally high values, minor extremely high values, common values, minor extremely low values, and exceptionally low values).

Results: Whatever the mortality conditions during the summer months, the mortality trajectories by age are exponential for both sexes: males die twice more than females at the age of 65 and their level of mortality linearly converges around the age of 97 to that of the females.

Discussion: Being male remains a major risk factor of mortality during heat waves. This issue was missed by previous epidemiological studies because almost all of them focused only on the relative increase in mortality and not on the sex specific mortality rates which implies being able to estimate the population at risk.

Our objective was to study the impact of an identical additional stress on male and female mortality with a quasi-experimental study design, using natural variations in summer mortality. The heat wave that struck Europe during the summer of 2003 led us to wonder about the possibility of using the magnitude of changes in mortality during the summer to better understand the characteristics of human mortality, especially the pattern of age-related increase in mortality known today as the mortality trajectories by age (Vaupel et al., 1998). Several studies have been devoted to patterns of increased mortality with age in order to draw general lessons about the limits of human longevity and the mechanisms of aging (see for instance (Economos, 1982; Gavrilov and Gavrilova, 1991; Greenwood and Irwin, 1939; Le Bras, 1976; Manton and Gu, 2001; Perks, 1932; Strehler and Mildvan, 1960; Thatcher, 1999; Vincent, 1951; Wilmoth, 1997)) but very few have been devoted to differences in mortality between the sexes in the hope of finding general laws.

We know that the level of mortality increases with age, but we have limited knowledge about the pattern of this increase. Mortality rates increase with age as individuals accumulate *sequelae* of past health events and augment the length of their exposure to various deleterious factors through their life course, resulting in a loss of physiological reserve and more generally a reduced ability to fight disease and death. The pattern of increased mortality with age is blurred because people are initially heterogeneous in terms of health capital. The premature death of the weakest changes, from age to age, the composition of the population in favor of those who were initially the most robust. The observed mortality rates correspond to groups of individuals that are not comparable over time. This heterogeneity of the population has been put forward to explain the observed trajectories which show that the age-specific mortality increases less rapidly from the age of 85 to reach a plateau circa 105–110 years (Maier et al., 2010), trajectories perfectly summarized by logistic models (Thatcher, 1999; Thatcher et al., 1998). The hypothesis proposed is that homogeneous groups of individuals would see their mortality regularly increase with age as in an exponential trajectory, but that the compositional changes of the population would lead to observe, from age to age, elements of lower and lower trajectories, giving the impression that the whole follows a logistic trajectory (Vaupel et al., 1979). This heterogeneity has often been reduced to an initial heterogeneity largely due to genetic differences.

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The increase in the number of centenarians, mostly females, we are witnessing today and the variations of this phenomenon from one country to another (Robine and Caselli, 2005; Robine and Paccaud, 2005; Robine and Saito, 2009; Robine et al., 2003) raises questions about the plasticity of human life to environmental conditions (Vaupel et al., 2003). Again, to simplify, it was thought until recently that the life span of adults was largely determined by the biology of the species and depended little on environmental conditions (Hayflick, 1996; Walford, 1985). In this article we examine whether the observed mortality trajectories by age are blurred by changes in environmental conditions.

There are numerous biological and psycho-social factors which may explain the differences in mortality between the sexes observed in developed countries (Oksuzyan et al., 2008). The usual approach has been to consider these factors as independent elements whose peculiar combinations explain the diversity of situations observed. Under these conditions the various authors seem to have been more interested in specific situations than in common features ((Gjonça et al., 1999; Ho et al., 2005; Jacobsen et al., 2008; Kolodziej et al., 2008; Kruger and Nesse, 2007; Preston and Wang, 2005) among the many references available). This can be explained by the fact that most authors do not believe that these differences could be inherently biological (Bobak, 2003) tough intra-uterine excess male mortality may essentially depend on biological factors (Stevenson and Bobrow, 1967; McMillen, 1979; Zeitlin et al., 2002; Vatten and Skjærven, 2004; Drevenstedt et al., 2008). However, some major features emerge from these studies. Excess male mortality clearly increases from adolescence to adult ages and then reduces in old ages. When studying mortality differentials, excess mortality refers to the excess of mortality of one group as compared with another, or with the rest of the population (Demopaedia, 2012). In this study, we use the absolute and the relative excess of mortality of males as compared to females to examine whether a sudden deterioration of environmental conditions affects or not the differences in mortality between the sexes.

The actions of the *human species* on the environment have significantly increased its average life expectancy, eliminated infant mortality, extended the typical adult life, indicated by the modal age at death, as well as the observed maximum life span and, in total, significantly reduced the variability of lifetimes. But these actions also created a large gap in survival between males and females which did not exist initially or very little. We do not yet understand the biological basis of this phenomenon that we tend to study only as an object of social science.

It is impossible to study human mortality under laboratory conditions, for example by altering the food availability or ambient temperature, as it can be done with yeast, worms or mice (Minois et al., 2009), to understand how environmental stress affects the differences in mortality between males and females. We should rely on animal models as with all other research topics which require recourse to experimentation. But the main animal models of aging, such as the mouse's, show no consistent difference in longevity between the sexes (Austad, 2010). This may explain the lack of interest of biologists for this important issue of life sciences, which is how and why do differences in survival appear between the sexes. In the same way that the vast majority of aging studies using mice measure the impact of experiments on the average survival time and maximum life span, opposing the experiences that extend the lifespan of mice to those that only reduce premature mortality, the provision of a model with systematic differences in survival by sex would likely lead to a classification between the experiences that increase the sex differences and those that reduce them. We would probably observe either additive or proportional effects, thus gaining insight into the biological mechanisms that enable the emergence of differences in survival between the sexes.

The study of the heat wave of the summer of 2003 revealed the lack of detailed knowledge about the seasonality of mortality in Europe and particularly in the summer period, when mortality is traditionally at its lowest in European countries. To measure the extent of changes in mortality during the summer and clarify the potential impact of seemingly minor changes in environmental conditions, such as daily variations in temperature and humidity on the trajectories of adult mortality by age, we have set categories summarizing the daily conditions of mortality during the summers of 1998 to 2003, distinguishing the summer of 2003 to control the potentially disruptive impact of the great heat wave. These daily conditions of mortality are not defined as very hot days that we could get used to in the long run but as days where mortality is either common or exceptional. We consider in this study that the days of usual mortality reflect days of usual stress while the days of exceptional mortality reflect days of exceptional stress, whatever the nature of the stress endured all the while taking into account that there might be a slight delay between the days of stress and the ensuing mortality.

The heat wave of 2003 was exceptional in its scope and the number of victims (Kovats and Ebi, 2006; Kovats and Hajat, 2008; Sardon, 2007), killing more than 15,000 people in France, 9000 in Italy, 7000 in Germany, 6000 in Spain, almost 2000 in England and more than 500 in the Netherlands (Robine et al., 2008). Heat waves are not a new phenomenon but are expected to increase with global warming (Kalkstein, 1991; McGeehin and Mirabelli, 2001). According to these authors, the main risk factors of mortality during heat waves are urban living, age, poverty and social isolation, as well as specific medications. We note that sex is never part of the list. The mortality associated with natural disasters has been regularly studied (Borden and Cutter, 2008) but as far as we know it has been rarely considered as a kind of natural experimental condition if we except a few studies of famines (Boyle and Grada, 1986; Pitkänen and Mielke, 1993; Grayson, 1990; Lumey and Van Poppel, 1994).

Our objectives are (1) to determine the extent of changes in the mortality of older adults during the summer – period of the year when mortality is both at its lowest and most regular in the temperate climate regions of Western Europe, (2) to specify the form taken by the trajectories of mortality by age under more homogeneous conditions of mortality, i.e., those of usual mortality and those of extreme mortality, separating those of extremely high and low mortality, and (3) finally, to clarify the differences between the sexes. In particular, we want to know whether the increased mortality associated with the sudden deterioration of environmental conditions adds an identical number of deaths for each sex in proportion to the population at risk.

1. Materials and methods

The analysis of daily mortality requires having the daily rates of mortality defined as the ratio of the number of daily deaths to the population exposed every day of the year. The numbers relating to daily deaths come from the study of the heat wave of 2003, in which one can find full details about their collection (Robine et al., 2008).

1.1. Definition of the geographic and time units of the study

This study examines the summer mortality of the 16 European countries included in the 2003 Heat Wave Study, namely Austria, Belgium, Croatia, Czech Republic, Denmark, England and Wales, France, Germany, Italy, Luxembourg, the Netherlands, Poland, Portugal, Slovenia, Spain, and Switzerland. It covers the years 1998–2003 and is limited to the population aged 65 and over. All calculations were performed at the regional level, corresponding to level 2 of the Nomenclature of Territorial Units for Statistics proposed by Eurostat (NUTS 2),[1] which led to the calculation of about 6 million daily rates of mortality corresponding to each gender

[1] http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction (accessed August 2nd, 2011).