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Exploring the impact of climate on human longevity

Jean-Marie Robine [a,*], François R. Herrmann [b], Yasumichi Arai [c], D. Craig Willcox [d,e,f], Yasuyuki Gondo [g], Nobuyoshi Hirose [c], Makoto Suzuki [d,e,h], Yasuhiko Saito [i]

[a] National Institute on Health and Medical Research, INSERM U988 and U710, France
[b] Department of Internal Medicine, Rehabilitation and Geriatrics, Geneva University Hospitals, University of Geneva, Switzerland
[c] Division of Geriatric Medicine, Department of Internal Medicine, Keio University School of Medicine, Tokyo, Japan
[d] Department of Human Welfare, Okinawa International University ,Ginowan, Japan
[e] Okinawa Research Center for Longevity Science, Urasoe, Japan
[f] Department of Research, Kuakini Medical Center, HI, USA
[g] Osaka University, Graduate School of Human Sciences, Clinical Thanatology and Geriatric Behavioral Science, Osaka, Japan
[h] Faculty of Medicine, University of the Ryukyus, Nishihara, Japan
[i] Nihon University Advanced Research Institute for the Sciences and Humanities, Tokyo, Japan

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ABSTRACT

The purpose of this study was to examine the impact of physical geographic factors and climate conditions on human longevity. The centenarian rate (CR) in 2005 was computed for Japan's 47 prefectures, whose geography and climate vary greatly. Several pathways, such as excess winter mortality, land use and agricultural production, possibly linking physical and climate factors with extreme longevity, were explored. The probability of becoming a centenarian varies significantly among the Japanese prefectures. In particular, the computation of CR_{70} demonstrated that the actual probability for individuals 70 years old in 1975 of becoming centenarians in 2005 was 3 times higher, on average, in Okinawa, both for males and females, than in Japan as a whole. About three quarters of the variance in CR_{70} for females and half for males is explained by the physical environment and land use, even when variations in the level of socio-economic status between prefectures are controlled. Our analysis highlighted two features which might have played an important role in the longevity observed in Okinawa. First, there is virtually no winter in Okinawa. For instance, the mean winter temperature observed in 2005 was 17.2 °C. Second, today, there is almost no rice production in Okinawa compared to other parts of Japan. In the past, however, production was higher in Okinawa. If we consider that long term effects of harsh winters can contribute to the mortality differential in old age and if we consider that food availability in the first part of the 20th century was mainly dependent on local production, early 20th century birth cohorts in Okinawa clearly had different experiences in terms of winter conditions and in terms of food availability compared to their counterparts in other parts of Japan. This work confirms the impact of climate conditions on human longevity, but it fails to demonstrate a strong association between longevity and mountainous regions and/or air quality.

1. Introduction

Since the initial research of Aristotle on the length of life, man has always looked for environmental explanations. Thus, when Buffon proposed that the duration of life is a characteristic of the species, he wrote that nothing can change the laws of mechanics governing human longevity except air quality, indicating that the oldest of the old are more commonly found in high countries, such as the mountains of Scotland or Switzerland (Buffon, 1749). Recent observations in Sardinia (Pes et al., 2011; Poulain et al., 2004) and in South Korea (Park et al., 2008) have revived the quest for environmental "*secrets*" (Willcox et al., 2008a). So, what is so special about the fresh air of the mountains, or, more generally, about the physical geographical factors and climate conditions that promote longevity?

Japan is surely one of the best places to tackle this question for at least five reasons: (1) Japan displays the highest life expectancy in the world (Robine et al., 2003) and enumerated more than 47,000 centenarians in 2011; (2) centenarians are not evenly distributed throughout the territory (Okamoto and Yagyu, 1998; Willcox et al., 2008b; Yagyu and Tauchi, 1997); (3) Japan, with the islands of the archipelago stretching out over 3000 km, exhibits great geographical diversity and the climate, although predominantly temperate, varies greatly (see supplementary material); (4) Japan has a wealth of data on its

Abbreviations: CR_{60} and CR_{70}, centenarian rate computed from age 60 and 70, respectively; AGG, absolute gender gap; RGG, relative gender gap; IMR, infant mortality rate; IPC, income per capita.

* Corresponding author at: INSERM U710 and U988, Centre de recherche de Val d'Aurelle, CRLC, 34298 Montpellier Cedex 5, France.
E-mail address: jean-marie.robine@inserm.fr (J-M. Robine).

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main physical factors and climate conditions as well as on almost all aspects of Japanese society; (5) Japan hosts quite a homogenous population with a largely dominant ethnic group made up of the Yamato people. There are also a couple of small minority groups, namely the Ainu, in Hokkaido and a specific ethnic group called the Ryukyuan in Okinawa and some parts of Kagoshima (Hanazaki, 1996).

2. Material and methods

2.1. Dependent variables

The first problem encountered in studying the geographical distribution of centenarians is the indicators used. Most of the authors content themselves with a ratio of the number of centenarians to the number of the total population even if they acknowledge that it is far from ideal (Caselli et al., 2006; Cockerham et al., 2000; Park et al., 2008; Poulain et al., 2004; Willcox et al., 2008b, 2008c). Indeed, there are many problems in interpreting these prevalence rates. In many countries, the number of births has radically changed over time. The size of the current population may have little to do with the size of the centenarian birth cohort. Some generations have been highly involved in economic cycles and wars, resulting in major population movements (Robine, 2007). To overcome these difficulties, it has been proposed that prevalence rates be replaced with the centenarian rate (CR_{60}), defined as the number of centenarians (age 100) per 10,000 people aged 60 years, forty years before. This relates the number of centenarians to their birth cohort. Age 60 has been proposed as a good compromise between eliminating most disruptions due to international migration and retaining most of the age-related mortality (Robine and Caselli, 2005).

In assessing the significance of the number of centenarians throughout Japan, we changed the threshold of 60 years to 70 years to account for Japan's internal migrations and the fact that Japanese workers retire later than European workers. Thus, we computed the centenarian rate (CR_{70}), defined as the number of centenarians per 10,000 people aged 70 years, thirty years before, using the 1975 and 2005 censuses. We have four dependent variables, i.e., male and female CR_{70} as well as absolute (AGG) and relative gender gap (RGG) in CR_{70}.

2.2. Japanese prefectures

Japan is divided into 47 prefectures. Their population size varies from less than one million inhabitants in seven prefectures to more than 12 million in Tokyo. Their surface area varies from less than 2000 km^2 in Kagawa and Osaka to more than 80,000 km^2 in Hokkaido (Statistics Bureau, 2008).

2.3. Independent variables

In a first series of statistical models, we attributed to each prefecture the altitude, latitude and longitude of its capital city, taking into consideration that most Japanese people are living in the prefectures' capital cities or in cities and suburbs agglomerated to them. A priori latitude brings more useful information, such as information on the duration of daylight, than longitude. In a second series of statistical models, we replaced these variables with more concrete descriptors of the physical environment. However longitude and latitude are always used to build the spatial correlation matrices of our statistical models (see below). In the last series of models we included a few additional variables to control for possible confounding factors such as the variation in the level of socio-economic status between prefectures or variation in early life conditions.

2.3.1. Physical and geographical factors

Physical and geographical factors comprise the proportion of the prefectures' surface area occupied by mountains, hill land, upland and lowland.

2.3.2. Climate conditions

Climate conditions comprise mean winter temperature, highest summer temperature, average relative humidity, average pressure, total precipitation, maximum precipitation per day, total snow fall, average wind speed, maximum wind speed, total hours of sunshine, clear weather days, cloudy weather days, snowy weather days and rainy weather days.

2.3.3. Confounding factors

To control for the existing social gradient among the Japanese prefectures (Cockerham et al., 2000; Okamoto and Yagyu, 1998), which can blur the results of our study, we introduced the income per capita recorded in 2005 in our final analyses and, to control for possible correlation between early and later mortality (Crimmins and Finch, 2006), we introduced the infant mortality rate (IMR) of the 1900 birth cohort as the closest proxy of the IMR of the 1905 birth cohort which is not readily available.

2.4. Pathways and intermediate variables

2.4.1. Excess winter mortality

It is difficult to think that physical factors directly impact human longevity. The relationships between geographical or climate variables and CR rates should go through intermediate variables such as food availability and health status. One possible cause linking climate variables to longevity is excess winter mortality. The seasonality of human mortality is well established with regular peaks of mortality in winter (Laake and Sverre, 1996; Mcmichael et al., 2008), essentially due to cardiovascular and respiratory diseases, triggered or worsened by cold temperatures (Analitis et al., 2008). Excess of mortality has also been observed in summer in relation to heat waves but to a lesser extent (Basu and Samet, 2002; Kovats and Hajat, 2008). To explore the role of excess winter mortality, we set two variables, the seasonal mortality index and the winter mortality index.

2.4.2. Land use and agriculture

A small number of factors, including diet and nutritional status, physical activity, health and social life, have been proposed as directly impacting human longevity. In this sense, these factors are proximal or immediate, being at the end of the various longevity pathways. By contrast, physical factors are exogenous independent factors, if we ignore the possible impact of human activity on climate. In that sense, if physical factors have an impact on human longevity, they are at the beginning of possible pathways. They are distant and remote factors. Diet and nutritional status depend primarily on food availability and eating behavior. If eating behavior essentially depends on culture, knowledge and education, and if food intake should depend on caloric needs, food availability chiefly depends on local production and trade (import, export). Even if eating behavior and caloric needs may partially explain local food production, it is, historically, dependent on the physical environment. Therefore, land use and agricultural production may be the first step on the pathway linking environmental factors to longevity through nutritional factors. To explore this pathway, we used five variables describing land use at the prefecture level and five variables specifying local food production.

3. Statistical analyses

First, we looked at univariate statistics for each variable in the study. Second, correlation analyses were conducted to examine the relationship among and between the groups of variables. Unless otherwise specified, all Pearson correlation coefficients mentioned in the text are significant at $p<0.05$. Third, we used simple and multiple spatial lag regression analyses in order to examine the effect of groups of independent or intermediate variables on the centenarian rate while taking into account spatial dependence. To identify the