Global Environmental Change 39 (2016) 234–243

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Heat-related mortality: Effect modification and adaptation in Japan from 1972 to 2010

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ARTICLE INFO

Article history:
Received 20 July 2015
Received in revised form 17 January 2016
Accepted 17 May 2016
Available online 18 June 2016

Keywords:
Heat
Mortality risk
Time-series
Adaptation
Effect modification
Socio-economic status

ABSTRACT

Excessive heat is a health risk, yet previous studies have observed a general decline in sensitivity to heat despite increasing temperatures. Conclusive evidence is lacking on whether long-term changes of this sensitivity can be attributed to specific adaptation measures, such as air conditioning, or should be linked to societal adaptation, such as improved healthcare systems or socioeconomic well-being. The aim of this study was to assess the variation of the association between heat and daily mortality during summer in Japan since the 1970s and to examine the influence of air conditioning (AC) prevalence, healthcare resources, and socioeconomic developments at the prefecture level on this variation.

We analyzed daily total, cardiovascular and respiratory disease mortality and temperature data from 1972 to 2010 for 47 prefectures. We used Poisson generalized linear model to estimate the effect of heat on mortality, random effects model to obtain the mean national effect estimates, and meta-regression to explore the impact of prefecture-level characteristics.

Average summer temperature has increased across Japan during the 39-year period. Excess mortality attributable to summer heat has decreased, with a national reduction of 20 (95%CI: 17, 22), 21 (95%CI: 18, 25), and 46 (95%CI: 36, 55) cases of total, cardiovascular, and respiratory deaths (per 1000 deaths). The increase of AC prevalence was not associated with a reduction of excess mortality over time. Prefectures and populations with improved economic status documented a larger decline of excess mortality. Healthcare resources were associated with fewer heat-related deaths in the 1970s, but the associations did not persist in the more recent period (i.e., 2006–2010).

Excess mortality due to heat has reduced in Japan, suggesting population adaptation. Yet, heat remains a significant health risk. Socioeconomic developments may play a role in heat adaptation. These findings may have implications for ensuring effective prevention of heat-related health impacts.

1. Introduction

Heat is a risk factor for excess cardiovascular and respiratory mortality (Armstrong et al., 2014; Aström et al., 2013; Basagaña et al., 2011; Basu, 2009; D'Ippoliti et al., 2010; Gronlund et al., 2014; Guo et al., 2014; Hertel et al., 2009; Michelozzi et al., 2009; Tobias et al., 2014; Zhang et al., 2014a,b). Health risks from heat are particularly pronounced in older persons, people taking

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http://dx.doi.org/10.1016/j.gloenvcha.2016.05.006
0959-3780/

medication, children, workers, and athletes exposed to high temperatures (Yeo, 2004). Medical conditions associated with extreme heat exposure range from heat cramps and heat exhaustion to heat stroke, and can lead to multi-organ failure and subsequent death (Alberini et al., 2011; Bi et al., 2011; Bouchama and Knochel, 2002; Bouchama et al., 2007; United States Environmental Protection Agency, 2006; Yeo, 2004).

Prior long-term temperature and mortality studies indicate a general decline in heat-related sensitivity despite increasing average summer temperatures (Bobb et al., 2014; Coates et al., 2014; Kyselý and Plavcová, 2012; Leone et al., 2013; Rocklov and Forsberg, 2008). What causes these changes has not yet been conclusively established (Bassil and Cole, 2010; Boeckmann and Rohn, 2014; Bouzid et al., 2013). Climate change scenarios project an increase in extreme temperature events in the near future globally (IPCC, 2014a), which could also lead to more intense periods of high temperatures in Japan (Chung et al., 2009; Honda, 2007; Honda et al., 2014). To protect human health from these increased risks, planned adaptation has been proposed as a mechanism to adapt to inevitable climatic changes (Biagini et al., 2014; IPCC, 2014b). The need for adaptation in Japan has been illustrated in previous assessments of heat-related mortality and morbidity (Chung et al., 2009; Honda, 2007).

Japan's climate varies between the three main islands of Hokkaido, Honshu and Kyushu, and ranges from subarctic in the North to subtropical on the Southern islands (Japan Meteorological Agency, 2014). All regions have distinct seasons, and both West and East Japan are characterized by hot and humid summers followed by cold or very cold winters (Japan Meteorological Agency, 2014).

Japan has a long history of institutional environmental and health policy (Imura and Schreurs, 2005; Tatara and Okamoto, 2009), a well-performing health system (Ikeda et al., 2011; Shibuya et al., 2011; Tatara and Okamoto, 2009), and the financial and institutional assets to design and implement adaptation strategies specific to heat under a changing climate (Martinez et al., 2011). This likely indicates a higher level of resilience. In addition to regularly occurring heat waves (Kondo et al., 2011), Japan is subjected to frequent earthquakes and thus well versed in dealing with environmental vulnerabilities (Ishii and Nagata, 2013). However, health-related adaptation research and policies have up to now focused predominantly on heat island mitigation (Homma, 2012; Honda et al., 2011; Inter-Ministry Coordination Committee to Mitigate Urban Heat Island, 2004; Prabhakar et al., 2013; Yamamoto, 2006).

This study aims at assessing the long-term changes of excess heat-related mortality during summer periods in Japan. Specifically, which local characteristics at the prefecture level might help explain these changes in excess mortality, and are these indicative of successful heat adaptation? This study is interested in socio-economic influences on heat mortality, as previous research has shown contradictory evidence for their impacts on the temperature-mortality relationship. For instance, while living in poverty has been characterized as an individual risk factor (Balbus and Malina, 2009), the role of neighborhood income in increased heat vulnerability has been suggested for the US Southwest (Harlan et al., 2013), but not for São Paulo in Brazil (Gouveia, 2003). To gain a better understanding of whether adaptation has caused long-term excess mortality reduction, we tested several hypotheses in our analysis of heat-related mortality. Such an approach has been suggested (Bobb et al., 2014), but has not yet been applied to the Japanese context. These alternative hypotheses include numbers of physicians, nurses, and hospital beds as proxy for healthcare access, prevalence of air conditioning (AC), and socio-economic profile of the examined prefectures.

2. Materials and methods

2.1. Data

Daily mortality records from 1972 to 2010 covering all 47 prefectures in Japan were obtained from the Ministry of Health, Labor and Welfare of Japan. Mortality data collection for Okinawa prefecture began a year later, from 1973. In Japan, the International Statistical Classification of Diseases and Related Health Problems 8th version (ICD-8) was used to categorize the cause of death between 1972 and 1978, the ICD-9 between 1979 and 1994, and the ICD-10 between 1995 and 2010. We extracted total mortality due to natural causes and cause-specific mortality defined according to the ICD system: total mortality (ICD-8 and ICD-9 codes 000-799, ICD-10 codes A00-R99), cardiovascular disease related death (ICD-8 codes 390-458, ICD-9 codes 390-459, ICD-10 codes I00-I99), and respiratory disease related death (ICD-8 and ICD-9 codes 460-519, ICD-10 codes J00-J99). Non-residents and deaths from external causes were excluded. We stratified the daily count of death cases by age group (i.e., $<$65, 65–74, and $\geq$75 years).

We obtained weather data from the Japan Meteorological Agency. Hourly measurements of ambient temperature from monitoring stations located in the capital cities in each prefecture (except for Saitama and Shiga prefecture, where stations from Kumagaya city and Hikone city were selected respectively) were used to compute the daily 24-h average and diurnal temperature range as proxies for personal exposure. We computed annual temperature anomalies defined as the deviation of the yearly summer temperature from the 20-year baseline (1972–1991) in each prefecture. These deviations were smoothed using the 5-year running means to observe temperature trend.

We collected information on specific socioeconomic conditions for each prefecture to assess the potential effect modification of area-level characteristics on the association between heat and daily mortality, including the influences due to changes of these characteristics over time. Data for the prevalence of AC, average annual income, average savings, and the Gini coefficients at the prefecture level were obtained from the National Survey of Family Income and Expenditure conducted every 5 years (Statistics Bureau Ministry of Internal Affairs and Communication Japan, 2009). Data for the prevalence of AC were based on households with two persons or more available from 1972 to 2009. Data for the average annual income and savings were available from 1974, while the Gini coefficients were available from 1979. Because data were not available for the entire study period, a linear rate of increase was assumed when calculating the changes of these variables over the 39-year period. Data for the annual economic power index, which measures the wealth of a prefecture, and the Laspeyres index, which measures the cost of living in each prefecture, were obtained from the survey of local public finance available from the Statistics Bureau of the Ministry of Internal Affairs and Communications (Ministry of Internal Affairs and Communication Japan, 2009). Both indices were available from 2003. The number of registered physicians, nurses (excluding assistant nurses) and hospital beds for each prefecture in year 1975 and 2004 were extracted from the Survey of Medical Institutions and Hospital Report conducted by the Ministry of Health, Labor and Welfare (Health Statistics Office Ministry of Health Labor and Welfare Japan, 2010). We expressed these variables in per-capita terms based on the Population Census for 1975 and 2005, respectively (Statistics Bureau Ministry of Internal Affairs and Communications Japan, 2011). To compute population density, information of land area for each prefecture was obtained from the 2005 survey conducted by the Ministry of Land, Infrastructure, Transport and Tourism (Geospatial Information Authority of Japan and Ministry of Land Infrastructure Transport and Tourism, 2005).