Issues in health risk assessment of current and future heat extremes

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**Background:** In assessing health risks relating to current and future heat extremes, it is important to include developing countries, because these countries are considered to be vulnerable to the impact of climate change due to inadequate public health infrastructure, nutritional status and so forth. However, it is usually difficult to obtain relevant information from these countries, also because of insufficient public health infrastructure.

**Objectives:** We invented a method that can be used for developing countries to assess the health risks of current and future extremes, but there still are some issues. We introduce and discuss these issues.

**Design:** We analysed time-series data with non-parametric regression models including generalised additive models, which controlled for time trends.

**Results:** When we controlled for year, the temperature/mortality relation was V-shaped, but when we controlled for season as well as year, the left side of the V-shape disappeared. Our month-specific analysis also revealed that winter months had higher mortality rates than other months, but there was no relation between mortality rate and temperature within each month during winter.

**Conclusions:** This suggests that, unlike heat effects, risks due to cold effects may not be ameliorated even if global warming occurs. We need to investigate the mechanism behind high mortality during winter months.

**Keywords:** heat extremes; Japan; epidemiology; excess mortality; generalised additive models

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In conducting global assessments of health risks associated with the impacts of ongoing climate change, one of the largest problems is that we need to address not only developed countries, but also many developing countries. In developing countries, the impact may be more serious than that in developed countries, yet the necessary data are sparse in general.

Among the various impacts, we have been assessing the health risk effect of current and future heat extreme. In this case also, there are problems in addressing developing countries in the assessment. Direct heat effects are usually evaluated with time-series studies or case-cross-over studies. In both types of studies, we need daily data for meteorological variables and outcome variables (mortality or morbidity). Also, for better prediction, we may need age, sex and cause-specific outcomes. However, it is impossible to obtain the daily outcome data for many developing countries. Hence, while it is important to develop sophisticated multivariate statistical models for developed countries, it is also very important to develop a simple method that can be applied to developing countries.

Thus, we have established our approach for prediction without using daily mortality data. The outline is as follows:

Reports in various areas in the world have shown that temperature-mortality relation is V-shaped, i.e. the mortality rate is high at both extremes of temperature, and between the extremes, there is a temperature at which the mortality is lowest. This temperature is called ‘optimum temperature’ (OT). Based on this relation, the excess mortality can be defined as shown in Fig. 1.

Some researchers also reported that the OT level is related to climate (1, 2). Curriero and colleagues reported that southern US cities had higher OT than northern US cities. To incorporate this characteristic in the prediction, we need a good climate index that can be used to infer the OT level. After exhaustive searching, we found that the 80–85th percentile value of daily maximum temperature is the best index for OT inference (3). Roughly speaking, if the 80th percentile value of daily maximum temperature in a certain area is 25°C, OT is also close to 25°C.

Based on the above finding and other assumptions explained in detail in Appendix A, we projected present...
and future risk due to heat-related deaths (4). In the assessment, however, we encountered some challenges: the days with extremely high temperatures were rare and the risk for these days could not be precisely estimated, hence we needed to pool the data; but pooling across areas was difficult because the OT levels were climate dependent. In our analysis, then, we pooled across chronological time.

In this article, we consider whether or not pooling across time was appropriate, and show another problem we found in controlling for time trend by generalised additive model. Also, we briefly discuss the net effect of climate change, making assessments that evaluate not only heat-related effects, but also cold-related effects.

**Present investigation**

**Methods**

**Data**

As we described above, we made our model as simple as possible to be generalisable to developing countries. Hence, we used daily maximum temperature as the only meteorological variable, and daily crude mortality rate (or daily number of deaths) as an outcome variable. Notably, our study showed that relative humidity did not confound the temperature–mortality relation in Japan (5).

The data for daily maximum temperature were obtained from Meteorological Agency, Japan, and that for daily mortality data were obtained from Ministry of Health, Labour and Welfare. The period of observation was from 1972 to 1995 (except for Okinawa, for which the period was from 1973 to 1995).

**Statistical methods**

We evaluated temperature–mortality relations by prefecture. In Japan, we have 47 prefectures; the northernmost prefecture is Hokkaido (43°N) and the southernmost prefecture is Okinawa (26°N). Tokyo is located in the middle of these two prefectures in terms of latitude (35°N). In the evaluation, we used smoothing spline (smooth.

**Fig. 1.** A schema for excess mortality due to heat.

spline) function from the statistics package of R language and environment for statistical computing and graphics (6). Degrees of freedom is another issue in semi-parametric regression; few degrees of freedom yield smoother curves, but if too few, then true relationships can be missed. Based on our exhaustive search, we set the degrees of freedom as six to obtain the best bias–variance trade-off (7). Using the above model, we determined the OT.

**Year-adjusted mortality rate**

In drawing smoothing spline curves, we encountered a problem with non-V-shaped relations in some prefectures (7). We could not initially explain why this phenomenon had occurred, but now we have found that it is due to the mechanism explained in Appendix B.

To illustrate, we replicate the temperature–mortality relation in Hiroshima, and compare it with the similar relation in which we replaced the ordinary mortality rate with year-adjusted mortality rate as described below.

In calculating year-adjusted daily mortality rate (YaM), we calculate two mean mortality rates in addition to ordinary daily mortality rate (DM): grand mean mortality rate (GM), i.e. average of DM for the entire observation period and year mean mortality rate (YM), i.e. average of the DM for each year. YaM is defined as:

\[
\text{YaM} = \text{DM} - \text{YM} + \text{GM}
\]

This procedure sets the average of YaM for each year identical to GM. In other words, this procedure explicitly eliminates the year trend.

**Generalised additive models**

Another method used to control for non-linear time trends was generalised additive models (8). In the analysis we used ‘mgcv’ package (9) from the R statistical environment. In controlling for time trend, we tried to make the degrees of freedom closer to the number of observation years to control for year trend, and seven times as large as the number of observation years to control for year and seasonal trend. Since time trend is explicitly addressed by adding the time term in the generalised additive models, we used the daily number of deaths, instead of the year-adjusted mortality rate.

**Month-specific analysis**

As will be described in the Results section, the year-controlled temperature–mortality relation and the year and season-controlled relations showed substantial differences. In order to explore these differences further, we evaluated month-specific temperature–mortality relations using smoothing spline curves.

**Results**

Fig. 2 shows the relation between daily maximum temperature and mortality in Hiroshima. Although we
used identical datasets except for mortality rate, the left panel shows a non-V-shaped relation, whereas the right panel clearly shows a V-shaped relation. This comparison suggests that not controlling for year fails to form a V-shaped relation.

To provide additional information for discussion, we show Fig. 3. Here, the distribution of daily maximum temperatures for Hiroshima was shown for 1972–1979, 1980–1989 and 1990–1995. During 1972–1979, there were some days with daily maximum temperature below zero, but no such day during 1990–1995. In contrast, number of days with daily maximum temperature beyond 35°C was much larger during 1990–1995 than that during 1972–1979. In Hiroshima, OT was in the upper twenties. The frequency distribution for OT appeared stable over time compared with the above difference for extremely cold and hot temperatures.

Fig. 4 illustrates the result of generalised additive model analyses. The top two panels show the results when only year was controlled for, and the bottom two panels show the results when year and season were controlled for. When only year was controlled for, the temperature-mortality relation was V-shaped, and the number of deaths was increasing over time. In contrast, when year and season were controlled for, the left-hand side of the V-shape disappeared. On the other hand, the high mortality rate during the cold season was observed in the time trend panel; with varying magnitude, every year had a winter spike.

Fig. 5 shows the relation between daily maximum temperature and year-adjusted mortality rate by month for some selected prefectures. The solid black, red and green lines on the left side are for December, January and February, respectively. The solid black, red and green lines on the right side are for June, July and August, respectively. Despite some fluctuations, the lines for winters do not appear to be temperature-related. In contrast, the lines for summer show higher mortality at higher temperatures. Another finding is that, not only within the prefecture, but also across prefectures, mortality rates within particular months in winter were

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**Fig. 2.** Relation between daily maximum temperature and mortality rate (Hiroshima, 65+ years old males, 1972–1995). Mortality for the right panel is the ordinary daily mortality rate (daily number of deaths divided by population for the year) and that for the left panel is the year-adjusted mortality rate.

**Fig. 3.** Distribution of daily maximum temperature in Hiroshima by period.

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more or less similar. Hokkaido, the coldest prefecture in Japan, had a much lower temperature range than other prefectures, yet its mortality rates in colder months were similar to those of the other prefectures.

**Discussion**

As Fig. 2 clearly shows, not controlling for time trends resulted in bias, with the non-V-shape problem. As explained in Appendix B, simultaneous changes in

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![Graphs showing temperature and mortality rates](image-url)
mortality rate and temperature distribution over time confounded the V-shaped temperature-mortality relation. Since temperatures have been rising due to climate change and mortality rates have been decreasing in many countries, it is not desirable to pool the data across time. This leaves us a problem of statistical instability for the relative risk on days with extremely high temperature. One possible solution, besides using generalised additive models, is to adjust for OT. This would at least reduce the variance of the relative risk on days with temperatures beyond the OT.

Another challenge we encountered in generalised additive models is how we can consider cold effects. Our analysis revealed that left side of the V-shape disappeared in all the prefectures; no prefecture showed higher mortality in colder days than in warmer days during winter when controlling for year and season. Some reports showed that V-shaped relations remained after controlling for season (2, 10). We are unsure why Curriero and colleagues’ results showed very high mortality on colder days, but in some figures from McMichael and colleagues’ report, a similar pattern to ours can be observed. Also Armstrong’s paper showed relation between cardiovascular mortality (which is the major cause of death that forms the V-shaped relation) and daily temperature in London, and the cold effect decreased substantially when controlling for influenza epidemics and other factors (11). At least our monthly analysis clearly showed that, for the colder months, temperature levels did not affect mortality within each month. Armstrong’s finding and our monthly analysis suggest that the cold side of the V-shape is mainly formed by influenza epidemic or other seasonal factors. This may incur reconsideration of ‘net effect’ evaluation of climate change on mortality, because global warming increases the number of extremely hot days and hence heat-related mortality increases, but decreasing numbers of very cold days may not attenuate high mortality in winter. There are other issues in the inference of health impact of climate change in developing countries, but our finding on cold effects showed the necessity of further investigations on the mechanism of high mortality during winter. Lag effect analysis is one of these investigations. At least we should not simply use the V-shaped curve in projecting net effect of climate change.

In the risk assessment of future climate change impact, how we address adaptation is always challenging. Adaptation can be divided into two categories; explicit policies to reduce the impact and spontaneous, collective phenomenon. The former cannot be estimated without conducting intervention studies, but the latter may be estimated using our finding, i.e. the relation between the 80th percentile value of the daily maximum temperature and OT; shifting the V-shaped curve from left to right makes the population less vulnerable to heat. For example, if the 80th percentile value of the daily maximum temperature rose from 26 to 28°, then setting the OT estimate at 26° would imply a 0% shift and 28° would imply a 100% shift.

Conclusion
In order to assess the risks due to climate change in developing countries, our finding that the 80th percentile value of daily maximum temperature was a good estimate of the optimum daily maximum temperature can be used, but there are some challenges.

We found that simultaneous changes in mortality rate and temperature distributions confounded the temperature-mortality relation in Japan. Since the temperature has been rising due to climate change and mortality rate has been changing in many of the countries, it is not desirable to pool the data across time.

The colder side of the V-shaped relation was formed due to higher mortality in winter months, but there was no cold effect within each month. This finding suggests that simple calculations of the net effect of global warming using V-shaped curves are questionable.

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Appendix A. Assumptions for the climate change risk projection

As described in the main text, it is often the case that the only available data is crude mortality rate in developing countries. Even when age and sex-specific mortality rate or cause-specific mortality rate are available, often the data are not sufficiently reliable. Hence, we tried to estimate the mortality rate at OT (MRot) using annual crude mortality rate (MRa). In our study (4), we used Japanese dataset. For each prefecture, we computed the ratio MRot/MRa, and obtained 0.9 for the average ratio of the 47 prefectures.

Another parameter we need is the relative risk for the excess mortality due to heat. To overcome statistical instability, we adjusted for OT in obtaining the relative risk estimate. We also recognised that the relative risk was close to unity if the temperature was close to OT, but became larger when the temperature was much higher. Hence we calculated relative risks for two temperature categories; our relative risk estimate based on Japanese 47 prefectures were 1.02 for daily maximum temperature between OT and OT + 5 and 1.10 for daily maximum temperature beyond OT + 5.

The existence of OT difference across the prefectures implies that OT may become higher when the global warming occurs. However we have no clue how fast this OT shift occurs, thus we assumed that OT is stable even when the global warming occurs.

Other assumptions we made were future scenarios; we used SRES A1B scenario (1) and Japanese climate model, CCSR/NIES/FRCGC Atmosphere–Ocean General Circulation Model.

Appendix B. Mechanism of forming non-V-shaped relations

As shown in Fig. 3, number of days with OT (around 28°C) did not change substantially, but number of days with extremely high temperature considerably increased over time. This suggests that the proportion of days in later years is higher for days with extremely high temperature than for days with OT. Also, the mortality rate has been decreasing in Japan.1 Hence the mortality rates were lower for more recent years. The combined effect of these two trends makes the pooled mortality rate for days with extremely high temperature lower than that for days with OT when the data are pooled across time.

For most of the prefectures, the effect was such that the slope of the right side of V was less steep; only for several prefectures, the V-shaped relation disappeared. However, even when there is V-shaped relation, the slope is confounded, and may not be valid if we pool the data across time.

Note

1. Fig. 2 is for 65+ years old age group and the mortality rate was decreasing. In contrast, the total number of deaths has been increasing as shown in Fig. 4.

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