Variation in reporting of heatstroke mortality: evidence from a multi-country study

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Summary

Background Heatstroke represents the most severe manifestation of heat exposure. Heatstroke is rare and under-reported, resulting in limited empirical data on its global incidence and burden. This study aimed to examine geographical variations and temporal trends in reported heatstroke mortality across multiple countries.

Methods We collected annual heatstroke mortality data from 34 countries participating in the Multi-Country Multi-City Collaborative Research Network between 2000 and 2022, using the ICD-10 code X30. Country-specific mortality rates were estimated using Poisson regression, alongside analyses of annual trends and associations with mean warm-season temperature. We also assessed the proportion of heatstroke deaths relative to both overall heat and extreme heat-attributable all-cause mortality.

Findings Heatstroke mortality rates varied widely across countries, with Japan reporting the highest rate (5·81 per 1 million population; 95% CI 4·43–7·62), followed by Cyprus (2·51; 1·36–4·61), and China (2·42; 1·21–4·85). By contrast, most countries in Europe, South America, and southeast Asia reported rates of less than one death per 1 million population. Heatstroke mortality increased over time in several countries and was associated with warm-season temperatures in most regions. The proportion of heatstroke deaths relative to overall heat-attributable mortality ranged from less than 1% in many countries to as close to 24% in Japan. When analyses were restricted to deaths attributable to extreme heat, the proportion of heatstroke deaths increased substantially.

Interpretation Our broad international assessment of heatstroke mortality highlights its distinct patterns compared with overall heat-attributable mortality. The observed variability likely reflects differences in recognition, reporting, and diagnostic practices, while climate exposure and health system capacity influence whether heat-related deaths are identified and recorded as heatstroke.

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Introduction

Climate change represents an escalating threat to human health, primarily through increased exposure to extreme heat and other extreme weather events. The Intergovernmental Panel on Climate Change projects that the frequency, intensity, and duration of heatwaves will continue to increase in the coming decades, exacerbating the global burden of heat-related mortality and morbidity.[1] Among various heat-related outcomes, heatstroke mortality sits on the extreme end of temperature-sensitive acute endpoints, resulting from thermoregulatory failure under prolonged heat stress.[2] Heatstroke is clinically diagnosed by a core body temperature typically exceeding 40·5°C accompanied by central nervous system dysfunction, with progression to multi-organ failure characterising severe disease and representing the principal pathway to death.[3]

Heat-related health risks are well established, mainly through all-cause mortality analyses attributing excess deaths to high temperatures,[4,5] and are expected to increase globally in the absence of effective mitigation and adaptation measures.[6,7] Many heat-related deaths occur through mechanisms other than heatstroke, including cardiovascular strain during heat exposure that can trigger acute events in people with pre-existing heart diseases, and are therefore not clinically identified or recorded as heatstroke. Although heatstroke is a severe and recognisable clinical outcome, it accounts for only a small portion of the total heat-related mortality burden.[3] Heatstroke is clinically diagnosed as classic heatstroke, primarily affecting older adults and other vulnerable populations, or exertional heatstroke, which mainly occurs among athletes and those who work outdoors.[3] Nonetheless, heatstroke deaths often attract public and

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For the **MCC Collaborative Research Network** see http://mccstudy.lshtm.ac.uk/

See **Online** for appendix

Research in context

Evidence before this study

We searched PubMed from database inception to Aug 1, 2025, without language restrictions, to identify studies on heatstroke mortality in relation to ambient temperature in humans, using the search terms "(heatstroke AND mortality AND temperature)". We identified 369 publications, of which the vast majority addressed clinical management of heat-related illness. Fewer than 15 studies provided population-based analyses of heatstroke mortality in relation to ambient temperature, nearly all restricted to single countries, short study periods, or specific heatwave events. Most international assessments of heat-related mortality do not explicitly examine heatstroke deaths. A systematic review identified only a small number of studies directly analysing heatstroke deaths in relation to ambient temperature exposure, underscoring the limited empirical basis for understanding global patterns of heatstroke mortality and their contribution to the overall heat-related mortality burden.

Added value of this study

To the best of our knowledge, this study provides the first large-scale international assessment of reported heatstroke mortality across multiple countries and climatic regions. Using harmonised mortality data from 34 countries participating in the Multi-Country Multi-City Collaborative Research Network, we quantified geographical variations, temporal trends, and associations with warm-season temperatures in heatstroke mortality rates. Notably, we directly compared certified heatstroke deaths with estimates of all-cause mortality attributable to heat derived from established temperature mortality models, including mortality attributable to extreme heat. Our findings reveal substantial cross-national heterogeneity in heatstroke mortality reporting, with heatstroke accounting for a small fraction of overall heat-attributable mortality in most countries but representing a much larger share of deaths during extreme heat events in some settings, particularly Japan. These results highlight systematic differences in the recognition, diagnosis, and certification of heatstroke that are not captured by excess mortality studies.

Implications of all the available evidence

The available evidence indicates that heatstroke mortality represents only a visible subset of the broader health burden attributable to heat, while also serving as a sensitive indicator of extreme heat exposure and health system response. The wide international variability suggests that differences in surveillance practices, clinical awareness, and death certification substantially influence reported heatstroke mortality rates. Improved standardisation of clinical definitions and reporting practices is essential to enhance international comparability and to better integrate heatstroke surveillance with population-level assessments of heat-related mortality.

media attention and feature prominently in disaster response strategies, which frequently emphasise recognition of heatstroke signs and symptoms, even though heatstroke is not the main cause of most heat-related mortality. The discrepancy between recorded heatstroke mortality and model-based estimates of heat-attributable deaths remains poorly characterised, complicating public health preparedness and risk communication. Notably, a systematic review found that only two of 62 studies directly examined heatstroke deaths in relation to temperature exposure.[8]

In this study, we aimed to examine heatstroke mortality reporting patterns, as well as geographical variations and temporal trends across countries participating in the Multi-Country Multi-City (MCC) Collaborative Research Network.[9] We also assessed the proportion of heatstroke mortality within estimates of heat-attributable all-cause mortality.

Methods

Data sources

We collected annual heatstroke death counts from 34 countries (Argentina, Australia, Brazil, Canada, Chile, China, Colombia, Costa Rica, Cyprus, Czech Republic, Ecuador, France, Germany, Iceland, Italy, Japan, Kuwait, Malaysia, Mexico, Moldova, Peru, Philippines, Portugal, Romania, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, UK, USA, and Uruguay) within the framework of the MCC Collaborative Research Network between 2000 to 2022.[9] The study period largely overlaps across countries, allowing for meaningful cross-national comparison.

Mortality data were restricted to deaths explicitly attributed to ambient heat, identified using the ICD-10 code X30 (exposure to excessive natural heat), recorded under external causes of mortality. In countries where X30 was unavailable, we collected data using code T67 (effects of heat and light) as a proxy to ensure comprehensive capture of heatstroke mortality.[10,11] All countries reported heatstroke mortality using code X30 from national statistical offices or departments of health, whereas Germany reported hospital-based heatstroke deaths coded as T67. Additional details on data sources and coding practices are provided in the appendix (pp 2–3).

We obtained annual national population estimates for the years with available mortality data from the World Bank's World Development Indicators Database,[12] to calculate country-specific annual heatstroke mortality rates. For countries reporting heatstroke data at subnational levels, population size was adjusted accordingly (appendix pp 2–3). Additionally, for each country, we obtained annual mean temperature data from the ERA5 reanalysis dataset and calculated the average temperature across the three hottest months as a proxy for annual warm-season temperature, commonly defined as June to August for countries in the Northern Hemisphere and December to February for those in the Southern Hemisphere.[13,14]

Statistical analysis

We conducted country-specific analyses to calculate annual average heatstroke mortality rates per 1 million population using overdispersed Poisson regression, with annual death counts as the outcome and the log of the population as an offset term. This approach accounted for population size variability and enabled direct estimation of mean mortality rates with corresponding 95% CIs. Age standardisation was not possible because individual-level data were unavailable for most countries due to confidentiality restrictions associated with the small case numbers. For each country, year-specific mortality rates were estimated by including year as a categorical variable, while temporal trends were assessed by modelling year as a continuous predictor. We also examined the association between annual heatstroke mortality rates and mean warm-season temperature at the country level.

We quantified the contribution of heatstroke deaths to all-cause mortality attributable to non-optimal heat exposure by extending the analytical framework used in a previous MCC study by Gasparrini and colleagues.[4] Specifically, the association between daily temperature and all-cause mortality was assessed using a two-stage time-series modelling approach. In the first stage, location-specific associations were estimated via quasi-Poisson regression models with distributed lag non-linear models. In the second stage, these associations were pooled at the country level using multivariate meta-regression. Overall heat-attributable mortality was calculated by integrating the excess risk above the minimum mortality temperature up to the maximum daily temperature. Extreme heat-attributable mortality was defined as mortality associated with temperatures greater than the 97·5th percentile of the local temperature distribution, consistent with previous definitions of extreme weather.[15,16] We then estimated the proportion of heatstroke deaths relative to both overall heat-attributable mortality and extreme heat-attributable mortality. To ensure valid comparisons, analyses were restricted to the years for which both heatstroke and all-cause mortality data were available within each country. Geographical consistency was also maintained by matching locations across datasets whenever possible. Further details on modelling specifications, aligned study periods, and study locations are provided in the appendix (p 4).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Annual heatstroke mortality rates varied widely across countries (figure 1). Japan reported the highest rate, with an annual average of 5·81 deaths per 1 million population (95% CI 4·43–7·62), more than double that of the next highest countries, Cyprus (2·51 [1·36–4·61]) and China (2·42 [1·21–4·85]). Elevated rates were also observed in

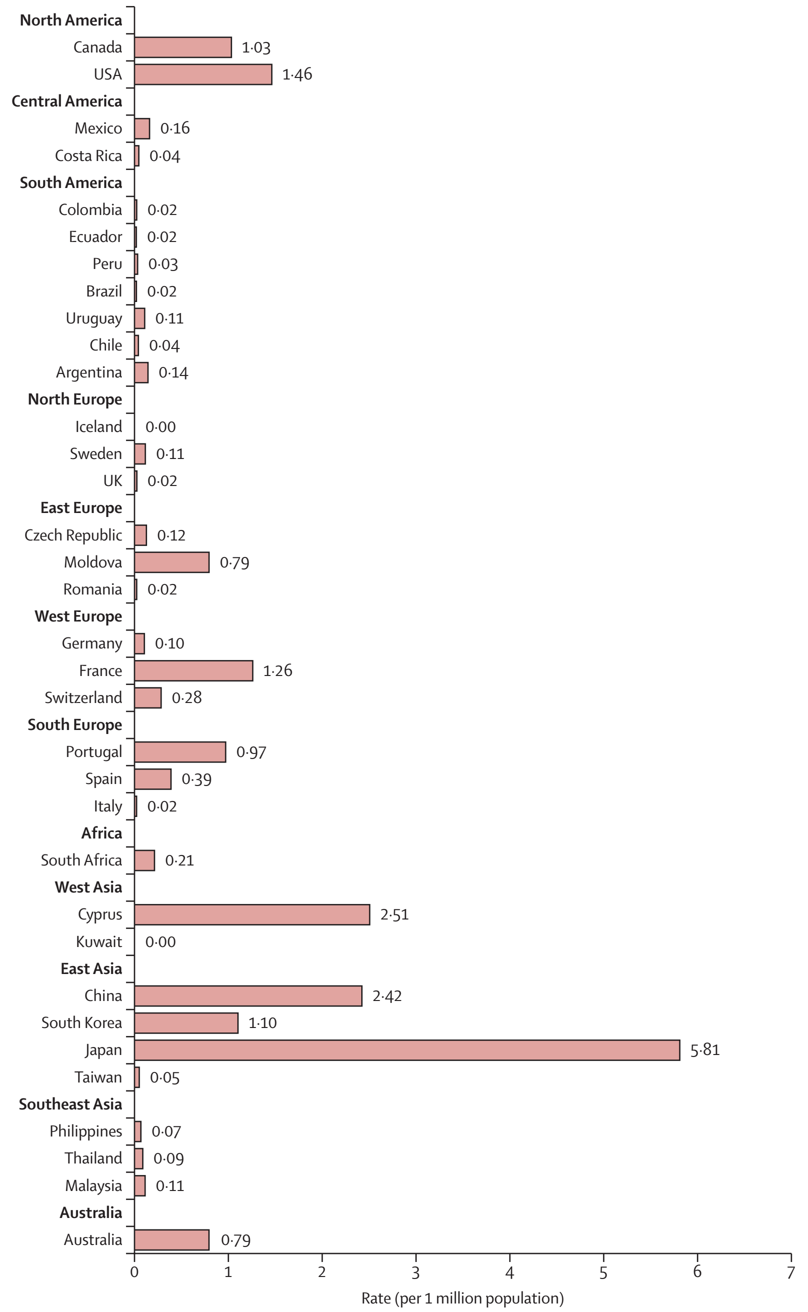

***Figure 1:* Heatstroke mortality rates by country (per 1 million population)**
Heatstroke mortality ICD-10 code X30 for all countries, except Germany (hospital-based mortality coded as ICD-10 T67). Data for Italy are regional (Lazio), and data for China are subregional (Shanghai and Suzhou). For 95% CIs, see the appendix (p 5).

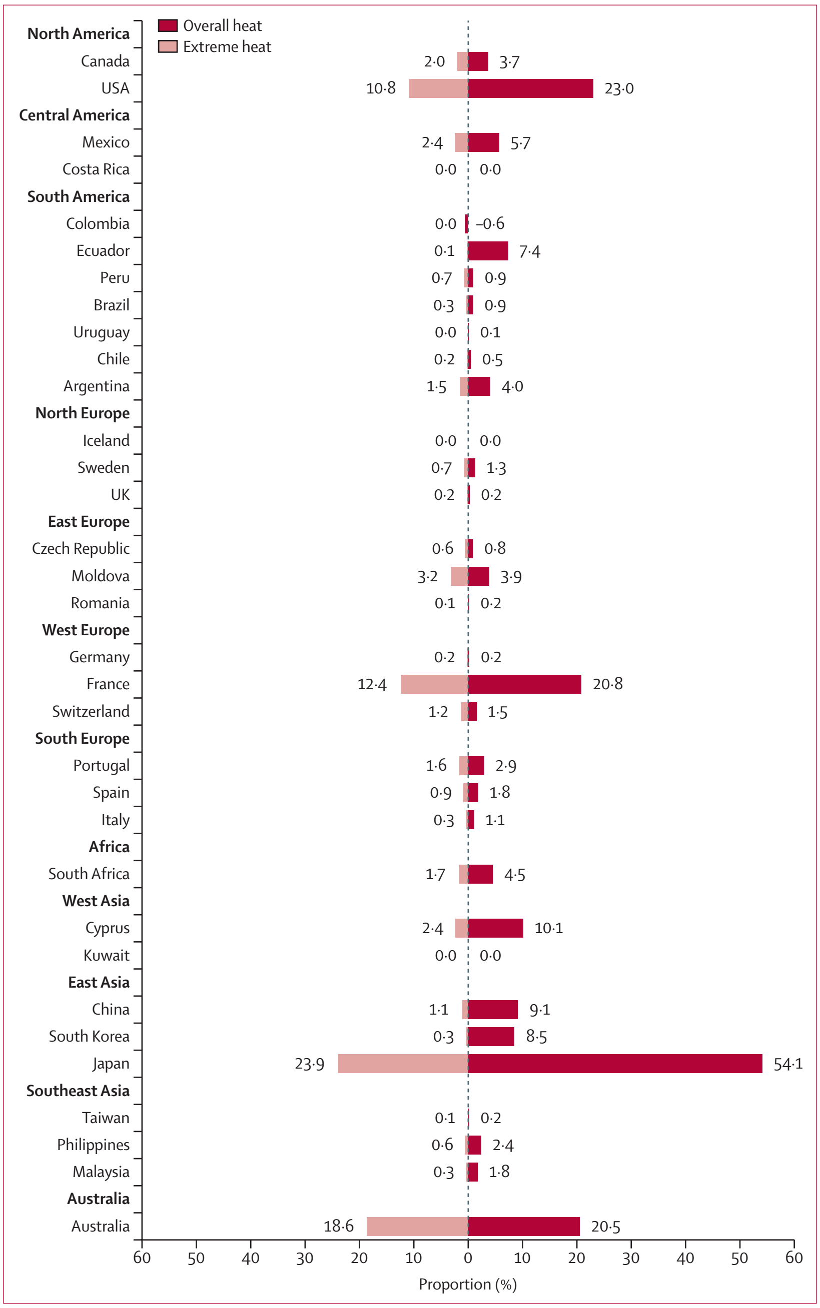

Figure 2: **Proportion of heatstroke deaths within overall and extreme heat-attributable all-cause mortality**
Heatstroke mortality ICD-10 code X30 for all countries, except Germany (hospital-based mortality coded as ICD-10 T67). Data for Italy are regional (Lazio), and data for China are subregional (Shanghai).

the USA (1·46 [1·24–1·73]), France (1·26 [0·87–1·82]), South Korea (1·10 [0·64–1·90]), and Canada (1·03 [0·47–2·25]). By contrast, many countries, particularly in Europe, South America, and southeast Asia, reported considerably lower rates, often less than one death per 1 million population (appendix p 5).

Several countries exhibited increasing trends in heatstroke mortality rates between 2000 and 2022. Although no uniform global pattern was observed, most of the increases occurred in recent years, particularly since 2018 (appendix p 7). Rising trends were identified in North America, Central America, and northwestern South America, but not in the Southern Cone. In Europe, many countries across all subregions showed increasing rates, although exceptions were noted, such as Romania and Spain. In Asia, upward trends were reported in most southeast Asian countries and Japan, but not in China, South Korea, West Asian countries, or Australia. A clearer and more consistent pattern emerged when examining the association between annual heatstroke mortality rates and warm-season temperature, with a positive relationship observed in most countries across all regions, except in South America and eastern Europe (appendix p 8).

The proportion of heatstroke deaths relative to total heat-attributable all-cause mortality varied substantially across countries (figure 2). Among countries with the highest proportions, Japan reported 23·9%, followed by Australia (18·6%), France (12·4%), and the USA (10·8%). By contrast, heatstroke accounted for less than 1% of heat-attributable deaths in most European, South American, and other Asian countries, with estimates close to zero or slightly negative in some settings. This finding likely reflects under-certification of heatstroke, as most heat-related deaths follow pathways not certified as heatstroke and are identified through excess mortality models rather than certified as heatstroke. Overall, countries with higher heatstroke mortality rates also reported a higher proportion of heatstroke deaths within overall heat-attributable mortality (appendix p 9). When the analysis was restricted to deaths attributable specifically to extreme heat, the relative contribution of heatstroke increased substantially. For instance, heatstroke accounted for 54·1% of extreme heat-related deaths in Japan, 23·0% in the USA, and 20·8% in France and 20·5% in Australia, indicating a stronger contribution of heatstroke during the most intense heat events (appendix p 6).

Discussion

To the best of our knowledge, this study presents the first international assessment of reported heatstroke deaths, drawing on large-scale mortality datasets from multiple countries across a wide range of climates and regions. We observed substantial variations in reporting practices and in the burden of heatstroke mortality, with annual rates from less than one death to nearly six deaths per 1 million population, and with the proportion of heatstroke deaths among all heat-attributable deaths varying from less than 1% to nearly 25%. These geographical differences should be interpreted with caution, as they likely reflect variability in the recognition and reporting of heatstroke rather than true underlying epidemiological differences in heat-related risks. From a population health perspective, however, this variability remains informative, as it highlights differences in the visibility of heatstroke within the broader burden of heat-attributable mortality across settings.

Over the study period, several countries exhibited increasing trends in heatstroke mortality, with the most pronounced rises observed in the USA, Japan, and countries in Central America, northwestern South America, much of Europe, and southeast Asia. These upward trends were more evident in recent years, especially since 2018, coinciding with rising temperatures, and could reflect genuine increases in exposure to extreme heat events, as well as population ageing and improved surveillance systems, clinical awareness, diagnosis, and certification practices of heat-related illness. No temporal trends were observed in countries where mortality data were not consistently available across the complete study period, especially in the most recent years (eg, China and South Africa), thereby limiting our ability to detect trends. In other countries, trends appear to be strongly influenced by isolated spikes during major historical heatwave years rather than by a sustained long-term increase (eg, Australia and Spain). This finding suggests that heatstroke mortality trends could be particularly sensitive to extreme events and to the temporal coverage of available data, underscoring the need for continuous, standardised surveillance to reliably assess long-term changes.

A positive association between warm-season temperatures and annual heatstroke mortality rates was observed in most countries. Given that heatstroke is an acute outcome closely linked to the frequency, intensity, and duration of heatwaves, this association suggests that rising temperatures, likely driven by climate change, reflect increased exposure to extreme heat events that contribute to the growing burden of heatstroke. However, temperature represents only one component of human heat stress, alongside humidity, wind, and radiant heat.[17] Additional contributing factors could include improved clinical recognition and reporting, the urban heat island effect, changes in occupational or social exposure patterns, and ageing populations with greater vulnerability.[18] For example, in our study, Japan, which has the highest proportion of adults worldwide aged 65 years and older, reported the highest heatstroke mortality rate. Population ageing is a global demographic trend that is likely to amplify heat-related health risks in many regions.[19] Moreover, observed reporting patterns could also be partially influenced by increased diagnostic sensitivity and improvements in death certification practices over time. In contrast, no significant association between warm-season temperature and heatstroke mortality was found in several South American and eastern European countries, possibly due to differences in population awareness, diagnostic capacity, and coding practices, which directly affect the reporting of heatstroke data.

Heatstroke is characterised by a marked elevation in core body temperature, typically exceeding 40·5°C, together with central nervous system dysfunction, arising when heat generation exceeds the body's capacity for heat dissipation and leads to dangerous internal heat storage.[3] Without timely treatment, this condition can progress to multi-organ failure through physiological cascades initiated by gut hyperpermeability and local tissue hypoxaemia, ultimately resulting in systemic inflammation and death.[20,21] Clinically, heatstroke is categorised into two types: classic heatstroke and exertional heatstroke.[3] Classic (or passive) heatstroke results from environmental heat exposure and impaired heat loss. This type is most commonly associated with insufficient sweating in older adults and other vulnerable populations,[22] with medications such as anticholinergics, non-selective β blockers, and anti-Parkinson's agents playing a contributory role.[23] Exertional heatstroke occurs during intense physical activity, when the combined effects of environmental heat and metabolic heat production overwhelm the body's thermoregulatory capacity. It primarily affects athletes and those who work outdoors,[24] and can be exacerbated by clothing or protective equipment that limits heat dissipation.[25]

Health system capacity should encompass the ability to recognise and manage suspected heatstroke, including access to emergency care and cooling, the use of standardised clinical protocols, documentation of core temperature and heat exposure, and accurate cause-of-death certification supported by medical examiner systems, autopsy practices, and trained coding and surveillance infrastructure. However, in practice, heatstroke is often underdiagnosed for several reasons. First, it is a rare condition that many physicians might not encounter during their training, leading to low clinical awareness, which likely varies across countries.[3] In addition, related clinical manifestations such as sepsis are often not recognised as consequences of heatstroke.[26] Second, in cases of classic heatstroke, particularly among older adults, patients are often admitted to hospital, reside in nursing homes, or are found deceased at home within 1–3 days of symptom onset, making retrospective diagnosis challenging.[27] Third, in older adults or individuals with chronic conditions, clinicians might attribute collapse or death to underlying diseases such as cardiovascular events, infections, or stroke, even though these outcomes might still be heat-related but occur through different mechanistic pathways, particularly when there is no clear history of heat exposure.[28] Fourth, among individuals experiencing homelessness, those with substance use disorders or intoxication at the time of death, and individuals with underlying neurological or mental health conditions, heatstroke is often misclassified on death certificates.[29,30]

A major challenge lies in the absence of standardised clinical definitions and coding practices across countries, which limits cross-national comparability and contributes to the misclassification and under-reporting of heatstroke in mortality statistics. In some health systems, diagnoses rely primarily on clinical presentation and core body temperature, whereas others place greater emphasis on contextual factors such as ambient temperature or exposure history. One possible explanation for the disparities observed in our study is that some countries might overdiagnose heatstroke due to heightened public awareness, extensive media coverage, and proactive recognition in emergency medical settings. In such contexts, physicians might be more likely to record heatstroke as a cause of death when heat exposure is suspected. For instance, during the 2021 Pacific Northwest heat dome in the USA and Canada, physicians in emergency departments appeared to overdiagnose heat-related illnesses, likely influenced by intense media attention and public health alerts.[31]

In our study, the mortality rate in Japan, a country known for its high public and institutional awareness of heatstroke risks, was nearly twice that of the next highest country and substantially higher than most others. However, a recent study in Tokyo compared the annual number of heatstroke deaths classified under ICD-10 code X30 on death certificates with those identified by the Tokyo Medical Examiner's Office, where cases underwent systematic examination, including autopsy, between 2006 and 2022.[32] The study found that autopsy-confirmed deaths accounted for approximately 90% of those reported on death certificates, suggesting minimal overdiagnosis despite heightened public and clinical awareness. This high concordance between autopsy findings and death certification aligns with our findings, in which heatstroke deaths accounted for more than 50% of all extreme heat-attributable deaths in Japan. Unfortunately, comparable validation evidence is largely absent for most other countries, highlighting the need to strengthen and harmonise heat-related health surveillance globally.

By contrast, many other countries might be underdiagnosing heatstroke due to scarce diagnostic capacity, low clinical awareness, or insufficient contextual information at the time of death certification, particularly when critically high core temperatures are not documented on admission and associated clinical signs along the heatstroke mechanistic pathway are therefore missed. This divergence in practice widens the visibility gap between officially reported heatstroke deaths and the broader, statistically inferred burden of heat-related mortality, risking under-communication of the true scale of heat-related health risks to both the public and policy makers. Reducing this visibility gap requires improved clinical awareness, the adoption of standardised diagnostic criteria, and more consistent certification and coding practices for heat-related deaths. These limitations have important public health implications. Although heatstroke deaths are highly visible in media reports and emergency response systems, they represent only a fraction of the overall population-level impact of extreme heat. Complementary approaches, including excess mortality analyses, syndromic surveillance, and integrated heat-health monitoring systems, are therefore essential to place clinically diagnosed heatstroke within the wider burden of heat-related mortality.

Several limitations should be acknowledged. Heatstroke remains underdiagnosed and inconsistently reported across settings. Despite our efforts, we were unable to investigate the causes of variability in clinical guidelines and reporting practices across countries, which presents a major challenge for international comparisons. Observed regional patterns should therefore be interpreted cautiously, as they could reflect both underlying epidemiological differences and variability in data capture and classification practices. In most countries, mortality data were available only as annual aggregated counts because of confidentiality constraints related to the small number of heatstroke deaths, thereby limiting the identification of affected subpopulations or differentiation between exertional and classic heatstroke. This limitation underscores the need for future studies that access individual-level clinical information to support more tailored prevention strategies. However, while our reliance on annual data limits the ability to assess short-term responses to heat events, year-to-year trends and temperature associations remain informative for long-term planning. In addition, for some countries, data were not available at the national level and were only reported at regional or subregional levels, which limits the representativeness of national estimates. Finally, our dataset under-represents several key regions that regularly experience extreme heat, including parts of Africa, southwest Asia, and the Middle East. As a result, areas with substantial heatstroke events, particularly during mass gatherings, are not captured in the analysis. For instance, more than 1300 likely heat-related deaths occurred during the 2024 Hajj in Mecca, yet such events are not reflected in our data.[33]

This study reveals wide international variations in reported heatstroke mortality, reflecting substantial differences in recognition, certification, and surveillance practices. These disparities highlight the need for global efforts to strengthen heat-related health monitoring, including clearer clinical guidance and standardised reporting systems. Improved comparability of data will be essential for understanding the full impact of extreme heat and for guiding effective public health responses under a changing climate.

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Contributors

AT, YH, and MH contributed to the study design and conceptualisation, and contributed to the method. AT and LM curated the data and implemented the analysis. AT and MH wrote the original draft. YH, LM, BAl, EL, DR, ST, MdSZSC, VH, AU, SdNPdS, SA, RMP, CI, PM, AVC, BAr, and AG revised and edited the draft. AT and MH were responsible for the decision to submit the manuscript. All authors discussed the results, commented on the manuscript, and approved the final version. AT and MH directly accessed and verified the underlying data reported in the manuscript.

Declaration of interests

BAl serves as a strategic advisor for ColdVestLLC. AG reports consultancy fees from University College London and payment from Reinsurance Group of America for a workshop. All other authors declare no competing interests.

Data sharing

Data were collected within the Multi-City Multi-Country Collaborative Research Network and are not publicly available due to restrictions imposed by the data sharing agreement with the Multi-City Multi-Country Collaborative Research Network participants of the included countries.

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