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Patterns of extreme temperature-related catastrophic events in Europe including the Russian Federation: a cross-sectional analysis of the Emergency Events Database

Heiko Brennenstuhl ,[1] Manuel Will,[2] Elias Ries,[3] Konstantin Mechler ,[4] Sven Garbade,[1] Markus Ries [1,5,6]

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For numbered affiliations see end of article.

Correspondence to
Professor Markus Ries;
markus.ries@uni-heidelberg.de

ABSTRACT

Objective To investigate reported extreme temperature-related catastrophic events and associated mortality on the European continent including the Russian Federation.
Design Cross-sectional respecting Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria.
Settings Data source: Emergency Events Database (EM-DAT).
Participants Search criteria: location—European continent including Russian Federation, time—years 1988 until 2019 (close of database 12 July 2019), catastrophic events—extreme temperatures.
Primary outcome measures Numbers of heat waves, cold waves, severe winter conditions and associated number of deaths, overall, and per country and year, respecting STROBE criteria.
Results The most frequent type of the 243 events recorded in EM-DAT were cold waves (54.7%). However, cold waves and severe winter conditions only accounted for 6460 deaths (4.5%), while heat waves were associated with 137 533 deaths (95.5%). The five most severe heat waves in 2003, 2006, 2010, 2013 and 2015 were associated with a total of 135 089 deaths. The most severe heat waves were geographically distributed over the Russian Federation (2010), as well as France, Italy, Spain and Germany, each in 2003.
Conclusion Although cold waves are more frequently reported in EM-DAT, heat waves are the major cause for temperature-related deaths. In order to better protect the public, it is important to address resiliency and vulnerability of populations at risk and age groups.

Strengths and limitations of this study

- ► This study quantitates the number, pattern and associated deaths of temperature-related catastrophic events (heat waves, cold waves, severe winter conditions) in Europe and the Russian Federation between 1988 and 2019.
- ► Data are derived from a comprehensive humanitarian disaster database (Emergency Events Database).
- ► The analysis relies on the accuracy of the reported data.
- ► Individual precise definitions of heat-related disasters may vary from country to country.

INTRODUCTION

In total 18 out of 19 of the hottest summers on record occurred after 2001, with 2016 marked by the warmest summer so far.[1] As climate experts expect this trend to progress, periods of extreme heat and cold could become more frequent in the future.[2] Exposure of humans to extreme temperatures causes a considerable danger to health. The average human body temperature is defined as 36°C to 37.5°C. A deviation of ±3°C can overexert the body's compensation mechanisms and cause substantial damage, potentially leading to death. Population groups such as the elderly and people with chronic (respiratory) diseases have a particularly high risk of being affected by extreme temperatures due to exhaustion of predominantly cardiorespiratory compensatory mechanisms.[3–5] However, the extent to which extreme temperatures affect humans is subject to complex biological, regional, geographical and social factors.[6 7]

Children have been previously identified as a vulnerable group for heat-related mortality.[8] One report covering observations in Budapest, London and Milan, from 1933 to 2001, 1993 to 2003 and 1999 to 2004, respectively, shows that between 0.8% and 1.4% of deaths due to heat waves were children under 14 years of age.[9] Xu *et al*[10] concluded that children under 1 year of age are particularly vulnerable to heat-related deaths. Both hot and cold weather influenced paediatric infectious diseases, for example, gastrointestinal or respiratory diseases and heat waves were associated with a higher incidence in renal disease, fever, and electrolyte imbalances.

In addition, excessive heat has been linked to considerable negative effects on mental health; it has been shown to increase psychiatric hospitalisation rates and prevalence of psychiatric disorders, predominantly depressive disorders, anxiety, insomnia and substance use disorders, but also aggressive behaviours.[11–19] Yet, the development of a psychiatric disorder after experiencing a (natural) disaster does not occur by default in all individuals.[20] This can be attributed to the construct of resilience, which describes the ability to overcome adverse situations without long-term negative effects.

Despite the great danger posed by extreme temperature situations, the public seems to be insufficiently aware of this problem. A comprehensive civil protection survey from 2009, conducted in 27 European countries with 26470 interviews listed flooding (45%), violent storms (40%) and industrial accidents (29%) as the three most feared disasters; heat waves were not mentioned at all.[21] It is important to render the occurrence of extreme temperatures and associated mortality transparent. We, therefore, directed our efforts in analysing temperature-related catastrophic events and associated mortality on the European continent including the Russian Federation between 1988 and 2019 in order to derive measures for a competent handling of the health hazard caused by temperature extremes.

METHODS

Data source

This is a cross-sectional study. Ethics approval was not required, because this study does not directly involve human research. Similar to a previous epidemiological study of disasters in Germany and France,[22] the present data analysis based on Emergency Events Database (EM-DAT), launched in 1988, maintained by the Centre for Research on the Epidemiology of Disasters at the School of Public Health of the Université catholique de Louvain located in Brussels, Belgium.[23] EM-DAT is a humanitarian database and captures data on more than 21000 disasters that occurred worldwide between 1900 and today. Disaster classification in EM-DAT is based on and adapted from the Integrated Research on Disaster Risk Peril Classification and Hazard Glossary.[24] As such, 'extreme temperature' is defined as 'a general term for temperature variations above (extreme heat) or below (extreme cold) normal conditions'. A 'heat wave' is defined as 'a period of abnormally hot and/or unusually humid weather', whereas a cold wave is defined as 'a period of abnormally cold weather'. Both weather extremes typically last two or more days. Severe winter conditions include snow, ice, frost and freeze. The exact temperature criteria for what constitutes a heat or cold wave varies by location.[24] Data sources for EM-DAT are UN agencies, governments, the International Federation of Red Cross and Red Crescent Societies, other non-governmental organisations, insurance companies, research institutes and press agencies.[23] For inclusion of a disaster in the EM-DAT, one or more of the following criteria must be fulfilled: (1) 10 or more people dead, (2) 100 or more people affected, (3) the declaration of a state of emergency or (4) a call for international assistance. A detailed description of the EM-DAT including structure, classification, variable descriptions and definitions is available here: https://www.emdat.be/guidelines.

Data query

EM-DAT was accessed over the internet on 10 July 2019. The following advanced search parameters were applied: period: 1988–2019; location: continent 'Europe' (as referenced by EM-DAT,[23] this includes the Russian Federation, which has a European and an Asian part); disasters classification: meteorological—extreme temperature (cold wave, heat wave, severe winter conditions). The following variables were extracted and analysed: catastrophic event start date, end date, country, disaster type, disaster subtype, total deaths, temperature magnitudes. The queried data set was transmitted to MR as validated data through email by EM-DAT on 12 July 2019. The last database update was 19 April 2019. Data were manually checked for plausibility. Two

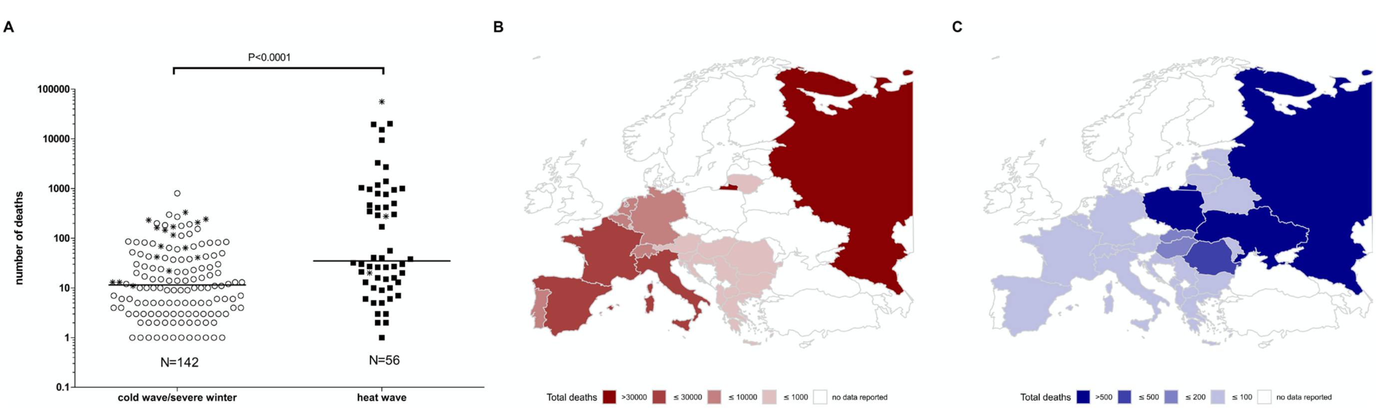

Figure 1 (A) Reported temperature-associated deaths in Europe for heat waves and cold weather (cold wave/severe winter conditions) between 1988 and 2019. Horizontal lines indicate medians. p=<0.0001 (Mann-Whitney U test). * designates events in the Russian Federation. Heatmap of total deaths associated with extreme temperature ((B) heat waves and (C) cold weather, that is, cold wave/severe winter conditions) throughout the European continent including the Russian Federation reported in the Emergency Events Database between 1988 and 2019.

hundred and forty-three events fulfilling the above criteria were reported, none of these events were filtered out. Missing data were not imputed. Temperature magnitudes were not reported for 125 out of 243 (51%) events, deaths were not reported for 45 out of 243 (19%) events. Duration of an event was calculated as the difference between start date and end date. If the dates were reported in EM-DAT with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision (ie, day of start or day of end was missing), duration was calculated in months assuming the whole month was affected by the event. For geographical mapping (figure 1) events were attributed to the precise regional location according to current geographical jurisdictions (eg, 'German Federal Republic—DFR' was recoded to 'Germany—DEU'). Data for population size of countries for a given year were retrieved from https://www.worldometers.info/world-population/population-by-country/ (Dover, Delaware, USA, accessed 13 March 2020).

Endpoints

Endpoints of this study were numbers of heat waves, cold waves and severe winter conditions and associated number of deaths (overall, and per country and year).

Statistical analysis

Strengthening the Reporting of Observational Studies in Epidemiology criteria, a quality assurance reporting guideline and checklist for observational studies, were respected.[25] Standard methods of descriptive statistics were applied. Variables were summarised using counts and percentages of the total study population. Differences between deaths associated with heat waves versus cold waves/severe winter conditions were calculated

Table 1 Reported catastrophic heat waves with more than 100 deaths on the European continent including the Russian Federation by country, year, duration and temperature magnitude between 1988 and 2019 in descending order by absolute number of deaths

Country	Year	Duration*	Temperature magnitude value (°C)†	Deaths	Population size	Deaths per 100 000 inhabitants
Russia	2010	3 months	40	55 736	143 479 274	38.8
Italy	2003	30 days		20 089	57 564 588	34.9
France	2003	19 days	43	19 490	60 251 588	32.3
Spain	2003	10 days	40	15 090	42 596 453	35.4
Germany	2003	1 month		9355	81 614 380	11.5
France	2015	41 days	40	3275	64 453 200	5.1
Portugal	2003	1 month		2696	10 429 612	25.8
France	2006	8 days	37	1388	61 508 926	2.3
Belgium	2003	14 days		1175	10 419 032	11.3
Switzerland	2003	1 month		1039	7 268 359	14.3
Netherlands	2006	8 days	34	1000	16 440 097	6.1
Netherlands	2003	13 days		965	16 200 951	6
Belgium	2006	2 months		940	10 619 475	8.9
Croatia	2003	1 month		788	4 388 895	18
UK	2013	1 month	40	760	64 984 018	1.2
Hungary	2007	1 month	41.9	500	10 024 149	5
Portugal	2005	3 months		462	10 508 495	4.4
Czechia	2003	1 month		418	10 239 136	4.1
Belgium	2015	5 days		410	11 287 940	3.6
Austria	2003	2 months		345	8 175 852	4.2
UK	2003	1 month		301	59 561 432	0.5
Slovenia	2003	2 months		289	1 987 862	14.5
Russia	2001	1 month	30	276	145 830 721	0.2
Luxembourg	2003	1 month		170	447 322	38

*Duration was calculated as the difference between start date and end date. If the dates were reported in the Emergency Events Database (EM-DAT) with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision, duration was calculated in months assuming the whole month was affected by the event.
†Missing values indicate that no data were reported to EM-DAT.

with the Mann-Whitney U test. A two-sided p value of equal or less than 0.05 was considered statistically significant. Statistical analysis and graphics including the spinogram were conducted with GraphPad Prism 5.04 (La Jolla, California, USA), and R (http://www.r-project.org). The European map was plotted using the R extension 'ggmap'.[26]

Patient and public involvement statement

Patients and the public were not involved in this study.

Limitations

The analysis of EM-DAT has some important limitations that have to be taken into account for the appropriate interpretation of the findings presented below.[22] The analysis relies on the accuracy of the reported data. Original source data verification was logistically not feasible and was, therefore, not undertaken. Epidemiological surveillance in individual single country included in the present analysis may vary leading to data heterogeneity. The definition of extreme temperatures, including heat and cold waves, may vary locally which could lead to ascertainment bias.[24] Assuming that a full month was affected when the start and end dates in EM-DAT were reported with a precision to the month only (tables 1 and 2) may overestimate the duration of events. Data in EM-DAT are not stratified by age, gender or social factors such as income levels, which would allow a more detailed analysis of vulnerable populations including children and facilitate better data-driven paediatric decision-making in catastrophic situations in the future. Depending on the precise research question, additional data may be gathered from other providers in the future. Nevertheless, EM-DAT is an authoritative state-of-the-art data source.[22]

RESULTS

Overall temperature-associated disaster pattern in Europe and the Russian Federation

Since 1988, 243 disasters associated with extreme temperatures were reported in Europe and the Russian

Table 2 Reported catastrophic cold waves and severe winter conditions with more than 100 deaths on the European continent including the Russian Federation by country, year, duration, disaster subtype and temperature magnitude between 1988 and 2019 in descending order by absolute number of deaths

Country	Year	Duration*	Disaster subtype	Temperature magnitude value (°C)†	Deaths	Population size	Deaths per 100 000 inhabitants
Ukraine	2006	21 days	Severe winter conditions	−30	801	46 607 395	1.7
Russia	2001	1 month	Cold wave	−26	332	145 830 721	0.2
Poland	2009	86 days	Cold wave	−35	298	38 351 916	0.8
Poland	2001	102 days	Cold wave	−25	270	38 529 582	0.7
Russia	2002	1 month	Cold wave	−50	242	145 215 700	0.2
Russia	2000	1 day	Cold wave	−7	232	146 404 903	0.2
Russia	1995	1 day	Cold wave		208	148 227 466	0.1
Poland	2010	4 months	Cold wave	−33	200	38 329 781	0.5
Poland	2005	5 months	Severe winter conditions	−32	191	38 368 949	0.5
Poland	2002	4 months	Cold wave	−25	183	38 488 647	0.5
Poland	2012	20 days	Cold wave		177	38 227 044	0.5
Russia	2012	11 days	Cold wave		170	143 993 892	0.1
Russia	1999	1 month	Cold wave		162	146 915 915	0.1
Poland	1999	1 month	Cold wave	−27	154	38 567 854	0.4
Russia	2001	2 months	Cold wave	−57	145	145 830 721	0.1
Slovakia	2010	4 months	Cold wave		122	5 398 673	2.3
Russia	2006	1 month	Severe winter conditions	−43	116	143 403 256	0.1
Ukraine	2012	1 month	Cold wave	−30	112	45 453 806	0.2

*Duration was calculated as the difference between start date and end date. If the dates were reported in the Emergency Events Database (EM-DAT) with a daily precision, duration was calculated in days. If dates were reported in EM-DAT with a monthly precision, duration was calculated in months assuming the whole month was affected by the event.
†Missing values indicate that no data were reported to EM-DAT.

Brennenstuhl H, *et al*. *BMJ Open* 2021;**11**:e046359. doi:10.1136/bmjopen-2020-046359

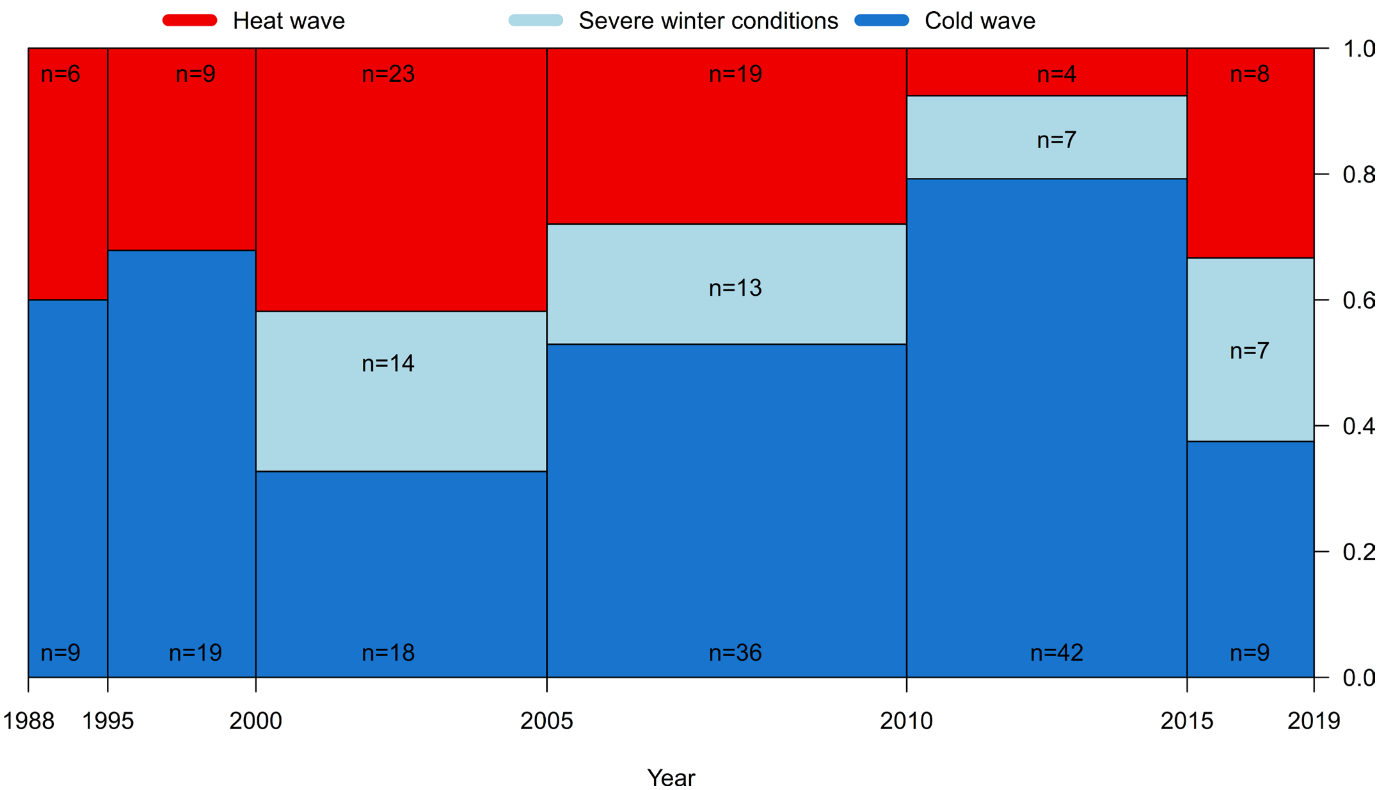

Figure 2 Spineplot frequency distributions of temperature-associated catastrophic events per 5-year period between 1988 and 2019. The height of the bars represents the percentage of each temperature-associated catastrophic event; the width is proportional to all events within this time period.

Federation. Catastrophic events associated with cold were more frequently reported than events associated with hot temperatures. There were 133 (54.7%) events associated with cold waves, 41 (16.9%) events due to severe winter conditions and 69 (28.4%) catastrophic events associated with heat waves. Overall, these disasters resulted in 143 993 deaths. Catastrophic heat waves were associated with 137 533 (95.5%) deaths. Catastrophic events due to cold waves were associated with 4983 (3.5%) deaths and severe winter conditions resulted in the death of 1477 (1%) people. The difference between deaths associated with hot extreme temperatures versus cold extreme temperatures (cold waves plus severe winter conditions) was statistically significant (p<0.0001, Mann-Whitney U test, figure 1A). Geographical mapping reveals the distribution of extreme weather-related events that led to high numbers of deaths throughout Europe (figure 1B,C, number of total deaths associated with cold and heat). For both, heat-related and cold-related events, the Russian Federation was among the countries with high numbers of reported deaths. Heat-related deaths were primarily reported in central-southern European countries, only little data were reported for northern European countries.

In the 32 years from 1988 to 2019, a median of 4 (IQR 2–12) events occurred per year, most catastrophic events occurred in 2012 (39=16%), 2005 (21=8.6%), 2010 (19=7.8%), 2009 (17=7%) and 2006 (17=7%). The overall distribution of event frequency for heat waves, cold waves and severe winter conditions over time is shown in figure 2. It is also important to note that during the period 2005–2010 the highest number of events was recorded in EM-DAT (n=68). Since 1988, the creation of EM-DAT, the 5 years with most reported deaths due to heat waves in Europe were 2003 (72 210 deaths), 2006 (3418 deaths), 2010 (55 736 deaths), 2013 (760 deaths) and 2015 (3685 deaths). In contrast, the 5 years with the highest number of reported deaths due to cold weather were 2001 (894 deaths), 2002 (435 deaths), 2006 (1077 deaths), 2010 (429 deaths) and 2012 (1056 deaths). Catastrophic heat waves and catastrophic cold waves including severe winter conditions on the European continent including the Russian Federation associated with more than 100 deaths since 1988 are listed in tables 1 and 2.

DISCUSSION

The present data suggest that heat waves in particular are a public health threat for the population on the European continent including the Russian Federation. Although less frequently reported than cold waves, heat waves were associated with significantly more deaths than cold temperature extremes. Considering the resilience of individuals to extreme temperature fluctuations, the body's own ability to acclimatise plays an important role. Research has shown that in addition to the length and intensity of heat waves, their occurrence over the course of the year has an impact on mortality.[27] Early heat waves

Table 3 Possible paediatric crisis measures and mitigation strategies for heat waves, adapted from[43 44]

Purpose	Measure
Ensure sufficient fluid intake (drinking)	► Increase fluid intake without waiting to feel thirsty. ► Raise awareness to caregivers to be alert to hydration levels in children, in particular bedridden or cognitively impaired individuals.
Avoid increase of body temperature (cooling)	► Establish cooling centres. ► Ensure intuitive and transparent awareness of localisation and opening times and stock with first aid materials, drinking water, games or activities for children. ► Establish spray parks and provide cooling services for children, ranging from toddlers to teens.
Educate caregivers (schools and childcare providers) and parents	► Ensure that adequate cooling measures are in place. ► Avoid strenuous activities during the hottest part of the day. ► Educate children on actions to reduce heat risks, which they can then share at home. ► Ensure that schoolchildren have adequate access to water and cool areas to rest.
Protect vulnerable populations	► Organise home outreach visits to vulnerable people. ► Evacuate vulnerable people from their homes to cooling centres.
Ensure medication safety for individuals with chronic health conditions	► Consider drug interference with sweating, thermoregulation, thirst, hydration, electrolyte balance, renal function, blood pressure, level of alertness and potentially increased toxicity due to dehydration. ► Check if medications need to be stored in a refrigerator.

were associated with higher mortality rates.[28 29] This could be explained, for example, by a lack of preceding acclimatisation. Putting humans and the results of this study in a more general evolutionary perspective, heat resilience evolved already in early members of the genus *Homo*, when the body's ability to adapt its metabolism according to surrounding temperature emerged to represent a major advantage.[30 31] *Homo sapiens* originated in the hot climates of Africa between 300 000–200 000 years ago with a typical linear physique indicative of heat-related adaptations, and dispersed to the more temperate climates of Eurasia only by ca. 60 000–40 000 years ago.[31–33] Tolerance towards cold in our species since the Palaeolithic appears to have been mostly dependent on behavioural support, evidenced in the archaeological record for example by specialised cold weather clothing and fire making.[34–36] The generally increasing reliance on cultural buffers in the recent evolution of our species likely lead to a general relaxation of selection pressures on anatomical, genetic and physiological adaptations to cope with extreme cold or heat.[37]

The 2009 European survey[21] in which heat waves were not mentioned at all as a feared disaster is remarkable given the known risks of heat waves and their substantial impact on the population, in particular in Europe during the year 2003. This may not be surprising, because, unlike flooding, violent storms and industrial accidents, heat waves are not visually dramatic—people die quietly in over-heated homes and apartments. Therefore, public health researchers need to work on and can make a difference with effective messaging to let the public know that heat waves can kill silently. There are excellent examples for comprehensive heat mitigation strategies and communication plans in order to protect vulnerable groups, including the elderly, children under 4 years of age, pregnant women, people with certain chronic medical or psychiatric conditions, patients undergoing certain pharmacological treatments, the poor, the frail, but also athletes and outside workers.[38] The French Republic has a comprehensive national heat plan elaborated by the French Ministry of Health and Solidarity, the public health system, and Météo France, the national weather agency. The plan comprises four escalating color-coded regional meteorological surveillance alert levels and four lines of action, that is, (1) prevention, (2) protection, (3) communication and (4) improvement by learning. The plan is usually activated during the vulnerable summer period between 1 June and 31 August each year. As a positive and very instructive example of intuitive public health communication, France uses a nationally aligned, visually enhanced public health advertising campaign to clearly communicate heat risks and mitigation measures to the public. This includes easy-to-understand messages such as 'drink water and keep cool', and 'avoid alcohol, eat sufficiently, keep blinds and shutters closed during the day, leave your window open at night, spray yourself with water and keep in touch with friends and family'.[39] French public health advertising includes messaging to the general public and specific focus groups including workers and employers, athletes and childcare facilities,[40] in addition to practical advice for the public on how to handle cooling technology.[41] As another direct consequence of the 2003 heat wave, air condition systems were installed in French nursing homes in order to protect older citizens.[42] Other examples for instructive heat wave mitigation strategies include the 'Heatwave Guide for Cities' developed by the Red Cross Red Crescent Climate Centre[43] and the 'beat the heat' campaign of the New South Wales Ministry of Health in Australia.[44] Possible paediatric mitigation strategies are presented in table 3.

Deaths due to extreme temperatures reported to EM-DAT include excess mortality compared with previous years for all causes of death and not only external causes such as hyperthermia or heat strokes. A study by Berko *et al*[45] analysed deaths due to external causes associated with heat, cold and other weather events in the USA and found, in general, more deaths being associated with cold (63%) than with heat (31%), although there was some regional variability. It is possible that the methodological focus on external causes of heat (hyperthermia) and cold (hypothermia) exposures may underestimate the overall mortality of heat and cold waves, in particular the impact of heat waves.

Maybe public perception of heat risk is low in part because people often associate heat waves with dehydration and heat stroke, when in reality, heat exacerbates cardiovascular, respiratory and other pre-existing conditions.

We consider the present findings generalisable within the context of the important limitations outlined in the methods section. Given the data in this report and the fact that temperature-related injuries are preventable, it is important to educate the European public about the danger of heat waves in order to appropriately (1) prevent, (2) respond to and (3) recover well from heat-associated disasters.

CONCLUSIONS

Although cold waves are more frequently reported in EM-DAT, heat waves were the major cause of temperature-related deaths in Europe and the Russian Federation. In order to better protect the public, it is important to address resiliency and vulnerability of at-risk populations and age groups.

Author affiliations
[1]Pediatric Neurology and Metabolic Medicine, Center for Pediatrics and Adolescent Medicine, University Hospital Heidelberg, Heidelberg, Germany
[2]Department of Early Prehistory and Quaternary Ecology, University of Tübingen, Tübingen, Germany
[3]Kurfürst-Friedrich Secondary School, Heidelberg, Germany
[4]Department of Child and Adolescent Psychiatry and Psychotherapy, Central Institute of Mental Health, Medical Faculty Mannheim, University of Heidelberg, Mannheim, Germany
[5]Center for Virtual Patients, Faculty of Medicine, University of Heidelberg, Heidelberg, Germany
[6]Center for Rare Diseases, University Hospital Heidelberg, Heidelberg, Germany

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ORCID iDs
Heiko Brennenstuhl http://orcid.org/0000-0002-6909-0003
Konstantin Mechler http://orcid.org/0000-0002-5322-7140
Markus Ries http://orcid.org/0000-0002-5054-5741

REFERENCES

1 Lenssen NJL, Schmidt GA, Hansen JE, *et al*. Improvements in the GISTEMP uncertainty model. *J Geophys Res* 2019;124:6307–26.
2 Perkins-Kirkpatrick SE, Lewis SC. Increasing trends in regional heatwaves. *Nat Commun* 2020;11:3357.
3 Bai L, Ding G, Gu S, *et al*. The effects of summer temperature and heat waves on heat-related illness in a coastal city of China, 2011-2013. *Environ Res* 2014;132:212–9.
4 Fouillet A, Rey G, Laurent F, *et al*. Excess mortality related to the August 2003 heat wave in France. *Int Arch Occup Environ Health* 2006;80:16–24.
5 Johnson H, Kovats RS, McGregor G, *et al*. The impact of the 2003 heat wave on mortality and hospital admissions in England. *Health Stat Q* 2005;25:6–11.
6 Xu Y, Dadvand P, Barrera-Gómez J, Yihan X, Payam D, *et al*. Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. *J Epidemiol Community Health* 2013;67:519–25.
7 Uejio CK, Wilhelmi OV, Golden JS, *et al*. Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health Place* 2011;17:498–507.
8 Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health* 2008;29:41–55.
9 Ishigami A, Hajat S, Kovats RS, *et al*. An ecological time-series study of heat-related mortality in three European cities. *Environ Health* 2008;7:5.
10 Xu Z, Etzel RA, Su H, *et al*. Impact of ambient temperature on children's health: a systematic review. *Environ Res* 2012;117:120–31.
11 Trang PM, Rocklöv J, Giang KB, *et al*. Heatwaves and hospital admissions for mental disorders in northern Vietnam. *PLoS One* 2016;11:e0155609.
12 Hansen A, Bi P, Nitschke M, *et al*. The effect of heat waves on mental health in a temperate Australian City. *Environ Health Perspect* 2008;116:1369–75.
13 Cusack L, de Crespigny C, Athanasos P. Heatwaves and their impact on people with alcohol, drug and mental health conditions: a discussion paper on clinical practice considerations. *J Adv Nurs* 2011;67:915–22.
14 Berry HL, Bowen K, Kjellstrom T. Climate change and mental health: a causal pathways framework. *Int J Public Health* 2010;55:123–32.
15 Padhy SK, Sarkar S, Panigrahi M, *et al*. Mental health effects of climate change. *Indian J Occup Environ Med* 2015;19:3–7.
16 North CS. Current research and recent breakthroughs on the mental health effects of disasters. *Curr Psychiatry Rep* 2014;16:481.
17 Ranson M. Crime, weather, and climate change. *J Environ Econ Manage* 2014;67:274–302.
18 Anderson CA. Heat and violence. *Curr Dir Psychol Sci* 2001;10:33–8.
19 Simister J, Cooper C. Thermal stress in the U.S.A.: effects on violence and on employee behaviour. *Stress and Health* 2005;21:3–15.
20 Havenaar JM, Bromet EJ, Gluzman S. The 30-year mental health legacy of the Chernobyl disaster. *World Psychiatry* 2016;15:181–2.
21 European Commission. Civil protection. Full report, 2009. Available: https://europa.eu/eurobarometer/surveys/detail/774 [Accessed 02 Jun 2021].
22 Ries M, Zielonka M, Ries N, *et al*. Disasters in Germany and France: an analysis of the emergency events database from a pediatric perspective. *Disaster Med Public Health Prep* 2019;13:958–65.

23 Guha-Sapir D, Below R, Hoyois P. EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium., 2019. Available: www.emdat.be [Accessed 02 Jun 2021].
24 Integrated Research on Disaster Risk. Peril classification and hazard glossary (IRDR data publication No. 1). Beijing: integrated research on disaster risk, 2014. Available: https://www.irdrinternational.org/knowledge_pool/publications/173 [Accessed 02 Jun 2021].
25 Vandenbroucke JP, von Elm E, Altman DG, *et al*. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. *Epidemiology* 2007;18:805–35.
26 Kahle D, Wickham H. ggmap: spatial visualization with ggplot2. *R J* 2013;5:144–61.
27 Anderson B, Bell M. Influence of Heatwave intensity, duration, and timing in season on heatwave mortality effects in the United States. *Epidemiology* 2011;22:S15.
28 Anderson GB, Bell ML. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environ Health Perspect* 2011;119:210–8.
29 Gasparrini A, Guo Y, Hashizume M, *et al*. Changes in susceptibility to heat during the summer: a multicountry analysis. *Am J Epidemiol* 2016;183:1027–36.
30 Ruff CB. Climate and body shape in hominid evolution. *J Hum Evol* 1991;21:81–105.
31 Ruff CB. Morphological adaptation to climate in modern and fossil hominids. *Am J Phys Anthropol* 1994;37:65–107.
32 Holliday TW. Body proportions in late Pleistocene Europe and modern human origins. *J Hum Evol* 1997;32:423–48.
33 Hublin J-J, Ben-Ncer A, Bailey SE, *et al*. New fossils from Jebel Irhoud, Morocco and the pan-African origin of Homo sapiens. *Nature* 2017;546:289–92.
34 Gilligan I. The prehistoric development of clothing: archaeological implications of a thermal model. *J Archaeol Method Theory* 2010;17:15–80.
35 Sandgathe D, Dibble H, Goldberg P. On the role of fire in Neandertal adaptations in Western Europe: evidence from Pech de l'Azé IV and Roc de Marsal, France. *PaleoAnthropology* 2011;2011:216–42.
36 Collard M, Tarle L, Sandgathe D, *et al*. Faunal evidence for a difference in clothing use between Neanderthals and early modern humans in Europe. *J Anthropol Archaeol* 2016;44:235–46.
37 Laland KN, Odling-Smee J, Myles S. How culture shaped the human genome: bringing genetics and the human sciences together. *Nat Rev Genet* 2010;11:137–48.
38 Haut Conseil de la santé publique. Recommendations Sanitaires Du Plan National Canicule 2014, 2014. Available: https://www.gouvernement.fr/risques/canicule [Accessed 02 Jun 2021].
39 Santé Publique France. Drink water and keep cool, 2020. Available: https://solidarites-sante.gouv.fr/IMG/pdf/covid_canicule_gp_400x600_gb_hd.pdf [Accessed 02 Jun 2021].
40 Ministère des solidarités et de la santé. Canicule et fortes chaleurs, 2020. Available: https://solidarites-sante.gouv.fr/sante-et-environnement/risques-climatiques/canicule [Accessed 02 Jun 2020].
41 Ministère des solidarités et de la santé. Vague de chaleur, 2020. Available: https://solidarites-sante.gouv.fr/IMG/pdf/systeme-rafraichissement.pdf [Accessed 02 Jun 2021].
42 Bosch X. France makes heatwave plans to protect elderly people. *Lancet* 2004;363:1708.
43 Singh R, Arrighi J, Jjemba E. Heat wave guide for cities, 2019. Available: https://www.climatecentre.org/downloads/files/IFRCGeneva/RCCC%20Heatwave%20Guide%202019%20A4%20RR%20ONLINE%20copy.pdf [Accessed 02 Jun 2021].
44 NSW Ministry of Health. Beat the heat - health tips for a safe season, 2013. Available: https://www.health.nsw.gov.au/environment/Publications/beat-the-heat-keep-healthy.pdf [Accessed 02 Jun 2021].
45 Berko J, Ingram DD, Saha S, *et al*. Deaths attributed to heat, cold, and other weather events in the United States, 2006-2010. *Natl Health Stat Report* 2014;76:1–15.