Excess Injury Mortality in Washington State During the 2021 Heat Wave

Joan A. Casey, PhD, MA, Robbie M. Parks, PhD, MA, Tim A. Bruckner, PhD, MPH, Alison Gemmill, PhD, MA, MPH, and Ralph Catalano, PhD, MRP

Objectives. To determine whether the 2021 Pacific Northwest heat wave resulted in excess injury (both unintentional and intentional) deaths.

Methods. With US death certificate data from December 29, 2013, to July 31, 2021, we generated weekly counts of injury deaths in Washington State and the rest of the country. We used time-series methods to identify excess injury deaths that may have occurred during and following the anomalously warm temperature period based on those expected from history and from simultaneous deaths in the remainder of the United States.

Results. Beginning the week including June 25, 2021 (heat wave initiation), 3 weeks exceeded the expected count of injury deaths in Washington State, with an estimated total of 159 excess injury deaths (95% detection interval = 122, 195) during the 3-week period.

Conclusions. The 2021 Pacific Northwest heat wave was associated with an increase in injury deaths.

Public Health Implications. Under global warming scenarios, heat waves of this magnitude will become much more common. Adaptation and planning efforts are needed to protect residents of the historically temperate Pacific Northwest for a range of health outcomes. (*Am J Public Health*. 2023;113(6): 657–660. https://doi.org/10.2105/AJPH.2023.307269)

AJPH June 2023, Vol 113, No. 6

Heat waves—extended periods of anomalously warm temperatures—are a critical public health concern, and a key driver for seeking adaptation measures against climate change.[1] Although assessments of the health effects of anomalously warm temperatures have largely focused on natural causes of deaths, including cardiorespiratory diseases and parasitic and infectious diseases, there is growing evidence of a robust association with deaths from injuries, such as from drownings, transport accidents, assaults, and suicides.[2–4] Previous work has also illustrated the risk of injury that heat poses among construction[5] and agricultural[6] workers in Washington State.

The Pacific Northwest region of the United States has a historically temperate climate. Late June and early July 2021, however, brought the highest temperatures ever recorded in the region.[7] Seattle, Washington, for example, experienced record heat on 3 consecutive days ending June 28, when temperatures peaked at 42°C, exceeding the previous recorded high by 3°C.[7] Attributed to climate change,[7] this period of anomalously warm temperatures centered on the Pacific Northwest, a region with minimal history of extreme heat events and thus relatively unprepared regarding infrastructure and prevalence of air conditioning.[8]

Such an anomalously warm temperature period may have induced excess injury deaths. Here, we define excess injury deaths as the difference between the observed number of injury deaths during a period of anomalously warm temperatures and a counterfactual scenario in which elevated temperatures had not occurred.[9] We estimate excess injury deaths, if any, during the anomalously warm temperature 2021 period, as the difference between injury deaths in Washington State expected from history and injury deaths in the rest of the United States at the same time as the heat wave.

METHODS

We used nationwide death certificate data from December 29, 2013, to July

31, 2021 (provisional at the time of analysis in December 2022). Death certificates in the United States use a "manner of death" classification, set by the Centers for Disease Control and Prevention, that includes "natural death," defined as "due solely or nearly totally to disease and/or the aging process." Based on data from 2010 to 2020, natural deaths accounted for approximately 89% of deaths in the United States.[10] We calculated the weekly count of Washington State injury deaths, also known as external or unnatural deaths, in the 396 study period weeks by subtracting natural from all-cause deaths.

We used time-series methods to determine whether the late June to early July 2021 heat wave in Washington State coincided with excess injury deaths. Our analyses, conducted using Scientific Computing Associates Software (Villa Park, IL), proceeded through the following steps:

1. We regressed the weekly count of injury deaths in Washington State on those in the remainder of the United States for the 390 weeks (i.e., December 29, 2013, through June 19, 2021) before the onset of the heat wave. This regression controlled determinants of temporal variation in injury death (e.g., long-term trends, seasonal trends, changes in death registration definitions and procedures) shared by Washington State and the rest of country.
2. We used Box–Jenkins methods to identify and model autocorrelation in the residuals of the step 1 regression. This step yielded a Box–Jenkins "transfer function" or equation that estimated Washington State injury deaths from those in the remainder of the United States and from autocorrelation specific to Washington State. Residuals of the transfer function satisfied the assumption of normal and independent distribution around 0.
3. We applied the Box–Jenkins transfer function devised in step 2, with coefficients fixed to those estimated for the first 390 weeks, to the full 396 weeks of observed data.
4. We combined the residuals from steps 1 and 3 and graphed them as well as the 95% detection interval of the residuals from step 1. We specified the lower and upper bounds of the detection interval as the negatively and positively signed product of 1.96 and the standard deviation of the residuals.

Because injury mortality (e.g., suicide) may lag exposure, and prior studies of heat and injury mortality relied on monthly data,[2,3] we evaluated excess injury mortality in the week of—and in the 5 weeks following—the heat wave. If the processes that yielded injury deaths in Washington State remained unaffected by the shock of the 2021 heat wave, the last 6 residuals (i.e., June–July 2021) in the graph produced in step 4 should have appeared randomly sampled from the prior 390 weeks. If, however, extreme ambient heat was associated with increased injury deaths, at least 1 of the last 6 residuals would rise above the 95% detection interval.

RESULTS

Between December 29, 2013, and June 19, 2021, weekly injury deaths in Washington State ranged from 56 to 154 (mean = 99; SD = 15). Figure 1 illustrates observed deaths throughout the study period, with noticeable upticks in injury deaths nationwide during the COVID-19 pandemic and in Washington State during the 2021 Pacific Northwest heat wave. As described in the Appendix (available as a supplement to the online version of this article at http://www.ajph.org), steps 1 and 2 produced a transfer function showing that weekly injury deaths in Washington State correlated with those nationwide. Time-series analyses found that injury death counts exceeded expected counts in the 3 weeks starting June 20 and ending July 10 (online Appendix, Figures A and B). During the week of June 20, injury deaths exceeded expected counts by 21 (1 injury death above the 95% detection interval of 20); during the week of record temperature (i.e., that ending July 3, 2021), injury deaths exceeded expected counts by 93 (72 injury deaths above the 95% detection interval of 20); and during the week beginning July 4, injury deaths exceeded expected counts by 45 (25 injury deaths above the 95% detection interval). We therefore estimated that the Pacific Northwest heat wave of 2021 coincided with 159 (95% detection interval = 122, 195) excess injury deaths in Washington State.

DISCUSSION

Our results show evidence of excess injury deaths after the 2021 Pacific Northwest heat wave, a 1-in-1000-years event caused by a ridge of high pressure resulting in a heat dome that trapped hot air over Washington State.[7] Anomalously warm temperatures plausibly influence injury deaths for several reasons. First, injury deaths vary seasonally in the United States,[11] which motivated us to explore whether temperature influences injury death rates. Second, plausible behavioral and physiological pathways exist

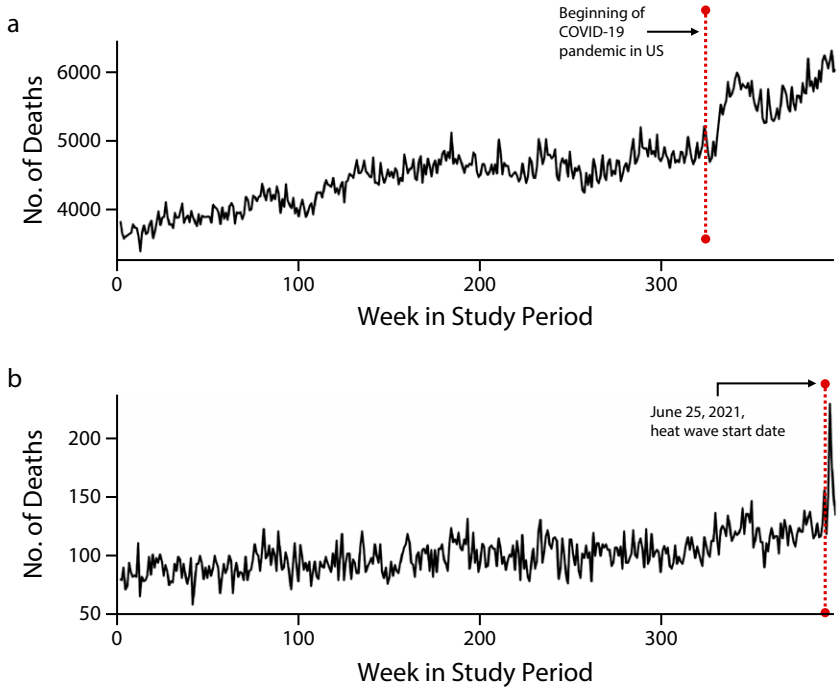

FIGURE 1— Observed Injury Deaths in (a) the United States and (b) Washington State: December 29, 2013–July 31, 2021

Note. The dashed red lines indicate the beginning of the COVID-19 pandemic (part a) and the beginning of the 2021 Pacific Northwest heat wave (part b). Observed injury deaths were obtained from the US Centers for Disease Control and Prevention and calculated as all-cause deaths minus "natural deaths."

for an association between temperature and injuries, such as changes in alcohol consumption, driving behavior, levels of anger and despair, and increased swimming.[12] Third, previous studies examining ambient temperature and injury outcomes in the United States have found positive associations.[2,3]

Public health programming during anomalously warm temperatures, intended to protect vulnerable communities from hazardous heat, should include ways to mitigate deaths from intentional injuries (such as assault and suicide) and unintentional injuries (such as falls, transport accidents, and drowning). Such programming will likely be needed more frequently given climate change.

We used provisional state-level death certificate data that do not specify cause or location of death (beyond state). Certain groups may be at disproportionate risk of the effects of heat, including older adults, workers, and others undertaking strenuous physical activity in uncooled spaces. Certain injury outcomes may also be more likely following heat exposure, but we could not disaggregate weekly injury deaths into subcategories (e.g., opioid-related mortality). Future studies should consider subcategories of injury and at-risk subgroups.

PUBLIC HEALTH IMPLICATIONS

Under climate scenarios with 2°C warming, models project that heat waves of this magnitude would occur every 5 to 10 years and that similar events would be 1.3°C hotter than today.[7] Public health interventions that broadly target the cause of injuries during periods of anomalously warm temperatures—for example, contacting isolated members of communities and campaigns promoting safe swimming or providing additional mental health services—should be a priority. AJPH

ABOUT THE AUTHORS

Joan A. Casey and Robbie M. Parks are with the Columbia University Mailman School of Public Health, New York, NY. Tim A. Bruckner is with the Program in Public Health, University of California, Irvine. Alison Gemmill is with the Johns Hopkins Bloomberg School of Public Health, Baltimore, MD. Ralph Catalano is with the School of Public Health, University of California, Berkeley.

CORRESPONDENCE

Correspondence should be sent to Joan A. Casey, PhD, MA, 3980 15th Ave NE, Room 254B, Seattle, WA 98105 (e-mail: jacasey@uw.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

PUBLICATION INFORMATION

Full Citation: Casey JA, Parks RM, Bruckner TA, Gemmill A, Catalano R. Excess injury mortality in Washington State during the 2021 heat wave. *Am J Public Health*. 2023;113(6):657–660.

Acceptance Date: February 19, 2023.

DOI: https://doi.org/10.2105/AJPH.2023.307269

CONTRIBUTORS

J. A. Casey and R. Catalano conceptualized the project. T. A. Bruckner and R. Catalano completed statistical analyses. J. A. Casey and R. M. Parks wrote the article. All authors provided feedback on analyses and article writing.

ACKNOWLEDGMENTS

This work was supported in part by the National Institutes of Environmental Health Sciences (R00ES027023, to J. A. Casey, and K99ES033742, to R. M. Parks).

CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

HUMAN PARTICIPANT PROTECTION

This research relied on publicly available data that were exempt from institutional review board review.

REFERENCES

1. Romanello M, McGushin A, Di Napoli C, et al. The 2021 report of the Lancet Countdown on health

and climate change: code red for a healthy future [erratum in *Lancet.* 2021;398(10317):2148]. *Lancet.* 2021;398(10311):1619–1662. https://doi.org/10.1016/S0140-6736(21)01787-6

2. Burke M, González F, Baylis P, et al. Higher temperatures increase suicide rates in the United States and Mexico. *Nat Clim Chang.* 2018;8(8):723–729. https://doi.org/10.1038/s41558-018-0222-x
3. Parks RM, Bennett JE, Tamura-Wicks H, et al. Anomalously warm temperatures are associated with increased injury deaths. *Nat Med.* 2020;26(1):65–70. https://doi.org/10.1038/s41591-019-0721-y
4. Lehmann F, Alary PE, Rey G, Slama R. Association of daily temperature with suicide mortality: a comparison with other causes of death and characterization of possible attenuation across 5 decades. *Am J Epidemiol.* 2022;191(12):2037–2050. https://doi.org/10.1093/aje/kwac150
5. Calkins MM, Bonauto D, Hajat A, et al. A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington State. *Scand J Work Environ Health.* 2019;45(6):588–599. https://doi.org/10.5271/sjweh.3814
6. Spector JT, Bonauto DK, Sheppard L, et al. A case-crossover study of heat exposure and injury risk in outdoor agricultural workers. *PLoS One.* 2016;11(10):e0164498. https://doi.org/10.1371/journal.pone.0164498
7. Philip SY, Kew SF, Van Oldenborgh GJ, et al. Rapid attribution analysis of the extraordinary heat wave on the Pacific coast of the US and Canada in June 2021. *Earth Syst Dyn.* 2022;13(4):1689–1713. https://doi.org/10.5194/esd-13-1689-2022
8. US Energy Information Administration. Nearly 90% of US households used air conditioning in 2020. 2022. Available at: https://www.eia.gov/todayinenergy/detail.php?id=52558. Accessed January 4, 2023.
9. Weinberger KR, Harris D, Spangler KR, Zanobetti A, Wellenius GA. Estimating the number of excess deaths attributable to heat in 297 United States counties. *Environ Epidemiol.* 2020;4(3):e096. https://doi.org/10.1097/EE9.0000000000000096
10. US Centers for Disease Control and Prevention. Underlying cause of death, 1999–2018. Available at: https://wonder.cdc.gov/ucd-icd10.html. Accessed September 7, 2021.
11. Parks RM, Bennett JE, Foreman KJ, Toumi R, Ezzati M. National and regional seasonal dynamics of all-cause and cause-specific mortality in the USA from 1980 to 2016. *Elife.* 2018;7:e35500. https://doi.org/10.7554/eLife.35500
12. Gallop. Climate change and wellbeing around the world. 2022. Available at: https://www.gallup.com/analytics/397940/climate-change-and-wellbeing.aspx. Accessed August 31, 2022.