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ORIGINAL ARTICLE

Disaster and Terrorism

Impacts of the 2021 heat dome on emergency department visits, hospitalizations, and health system operations in three hospitals in Seattle, Washington

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Abstract

Objectives: Extreme heat events (EHEs) are associated with excess healthcare utilization but specific impacts on emergency department (ED) operations and throughput are unknown. In 2021, the Pacific Northwest experienced an unprecedented heat dome that resulted in substantial regional morbidity and mortality. The aim of this study was to examine its impact on ED utilization, unplanned hospitalization, and hospital operations in a large academic healthcare system.

Methods: Retrospective electronic medical records from three Seattle-area hospitals were used to compare healthcare utilization during the EHE compared to a pre-event reference period within the same month. Interrupted time series analysis was used to evaluate the association between EHE exposure and ED visits and hospitalizations. Metrics of ED crowding for the EHE were compared to the reference period using Student's *t*-tests and chi-squared tests. Additionally, multivariable Poisson regression was used to identify risk factors for heat-related illness and hospital admission.

Results: Interrupted time series analysis showed an increase of 21.7 ED visits per day (95% confidence interval [CI] = 14.7, 28.6) and 9.9 unplanned hospitalizations per day (95% CI = 8.3, 11.5) during the EHE, as compared to the reference period. ED crowding and process measures also displayed significant increases, becoming the most pronounced by day 3 of the EHE; the EHE was associated with delays in ED length of stay of 1.0 h (95% CI = 0.4, 1.6) compared to the reference period. Higher incidence rate ratios for heat-related illness were observed for patients who were older (incidence rate ratio [IRR] = 1.02; 95% CI = 1.01,1.03), female (IRR = 1.47; 95% CI = 1.06, 2.04), or who had pre-existing diabetes (IRR = 3.19; 95% CI = 1.47, 6.94).

Conclusions: The 2021 heat dome was associated with a significant increase in healthcare utilization including ED visits and unplanned hospitalizations. Substantial impacts on ED and hospital throughput were also noted. These findings contribute to the understanding of the role extreme heat events play on impacting patient outcomes and healthcare system function.

KEYWORDS
climate change, disaster, heat, heat wave, operations

1 | INTRODUCTION

1.1 | Background

Extreme heat events (EHEs) have become more frequent and intense in the context of anthropogenic climate change.[1] Prior work has demonstrated considerable health impacts of these EHEs including heat illness, renal injury, and exacerbations of chronic disease and mortality.[2–4] Emergency medicine is likely to be disproportionately affected by shifts in extreme heat and other climate-sensitive hazards.[5]

1.2 | Importance

Western North America experienced an unprecedented extreme heat event in June 2021, when daily maximum temperatures exceeded 107°F in Seattle, Washington, and 114°F in Portland, Oregon; these extreme temperatures were sustained for over 3 days in Seattle, with elevated temperatures lasting for weeks throughout the region.[6] A significant number of emergency department (ED) visits for heat-related illness (HRI) were noted throughout the Northwestern United States during this period using syndromic surveillance data, and approximately 740 excess deaths were attributed to this EHE in British Columbia.[7–9]

Prior efforts have evaluated the health impacts of the 2021 EHE through healthcare claims data in Seattle and Portland, identifying increased rates of heat-related ED visits for a range of conditions.[10] Regional claims data, however, obscure the departmental- and system-level impacts of the EHE within the region.

1.3 | Goals of this investigation

Here, two analyses are conducted to evaluate (1) heat exposure and associated impact on ED volume and throughput, and (2) patient-level impacts on presentation for HRI and risk factors associated with admission, exploring the impacts of this unprecedented EHE on patient and system outcomes within the University of Washington (UW) Health System.

2 | MATERIALS AND METHODS

2.1 | Data sources

Retrospective electronic health record data were sourced from three Seattle hospitals: UW—Montlake, UW—Northwest, and Harborview Medical Center. The UW Institutional Review Board approved this study (ID: STUDY00014587). Daily maximum air temperatures were recorded by the Seattle-Tacoma International Airport monitoring station and provided by Climate Data Online from the National Oceanic and Atmospheric Administration, National Centers for Environmental Information.[11,12]

2.2 | Study inclusion criteria

The study window was defined as the index period encompassing the heat dome event from June 26 to 28 (Sat–Mon), 2021, as well as a reference period 3 weeks prior from June 5 to 7 (Sat–Mon), 2021. Inclusion in the study window was based on date and time of ED arrival. The reference period was chosen within the same month to limit confounding from secular trends and matched on day-of-week.[13] Diagnoses were coded according to the International Classification of Diseases, 10th Edition (ICD-10 codes). All diagnoses recorded during the visit were included in the analyses. Diagnoses were grouped using Clinical Classifications Software Refined (CCSR) groupings available from the Agency for Healthcare Research and Quality (AHRQ).[14] Diagnoses of interest were captured similarly to previous literature describing HRI during heat waves, including heatstroke, dehydration, and electrolyte derangements.[15,16] The full list of diagnosis category definitions, including HRI, can be found in Table S6. Pediatric cases were excluded due to the predominantly adult population cared for at these three hospitals and the small sample size of pediatric patients.

2.3 | Statistical analyses

Descriptive analyses were used to describe demographic and clinical characteristics for the overall cohort, as well as the HRI-specific cohort during the EHE and reference period. Excess ED visits and unplanned hospitalizations were reported as unadjusted values. Unplanned admissions were defined as hospital admissions that resulted from an ED visit.

Interrupted time series analysis (Stata package: *itsa*) was used to compare the relationship between the EHE and ED visit volume. This method, common in epidemiological studies, was selected for its ability to compare two time periods and to identify whether the exposure had an effect significantly greater than the underlying secular trend.[17,18] Two models were specified: one with ED visits as the dependent variable and one with admissions as the dependent variable. For both, model covariates were as follows: time (by day of month), the pre-EHE period (June 1–25), the EHE period (June 26–28), and the maximum daily temperature. The Cumby–Huizinga test was used to detect autocorrelation (Stata package: *actest*). Newey–West standard errors and 95% confidence intervals (CIs) for coefficients were estimated by ordinary least squares regression.

Multivariable Poisson regression models were used to evaluate risk factors for HRI diagnosis among ED visits across both EHEs and reference periods. Model covariates were clinically selected a priori to include insurance status, sex, race, age, and potential comorbid conditions of diabetes mellitus (DM) and cardiovascular and respiratory diseases. Model outputs were reported in terms of incidence rate ratio (IRR) and 95% CIs.

ED crowding and process measures were compared for the EHE and reference period using chi-squared tests for binary variables and Student's *t*-test for continuous variables. The measures evaluated were as follows: 48-h return visit rate, occupancy rate, and a modified ED Work Index Score (EDWIN) score. Note that 48-h return visit rate was defined as number of patients with repeat ED visit within 48 h of initial visit. Occupancy rate was defined as number of patients in ED divided by number of licensed ED bays, calculated hourly. The numerator included all patients that checked into the ED, regardless of location (eg, waiting room, boarding, hallway beds, or multi-use rooms), as in prior studies.[19] The modified EDWIN score has been previously described and was calculated hourly as a proxy for ED crowding as shown below, with higher scores indicating greater ED crowding.[20]

$$\text{EDWIN} = \Sigma\,(n_i \times t_i)\,/\,(\text{N}_\text{A} \times \text{B}_\text{T})$$

where $n_i$is the number of patients in the ED in triage category i; t_i is the triage category; N_A is the number of attending physicians on duty, and B_T is the number of treatment bays. The modified EDWIN score differs from the original EDWIN score in that it does not remove admitted patients in the ED from the total count of patients in the ED, and it reverses triage category numbers 1–5 such that higher acuity triage classifications are associated with a higher number (eg. Emergent = 5). Of note, we defined B_T as the number of licensed ED treatment bays as in the original EDWIN score, in contrast to the modified EDWIN score, which reports unlicensed treatment bays such as hallways beds in the count of B_T.

Process measures were analyzed only for patients who were admitted to the hospital or discharged from the ED; patients with other ED dispositions such as expired, transferred, or left without being seen, eloped, or left against medical advice were excluded from analysis. Process measures evaluated were time from patient arrival to being roomed in the ED, time from patient arrival to being first seen by an ED provider, and total ED length of stay. Stata 15.1 (StataCorp) was used for all statistical analyses.

The Bottom Line

In a study examining the impact of the 2021 Pacific Northwest heat dome on emergency department (ED) utilization, unplanned hospitalization, and hospital operations in a large academic healthcare system, the authors found nearly 22 additional ED visits per day, almost 10 additional unplanned hospitalizations per day, and an increase in ED length of stay of 1 hour during the event compared to a reference period. These results suggest that the 2021 Pacific Northwest heat dome was associated with a significant increase in ED visits and unplanned hospitalizations, with negative impacts on ED throughput.

3 | RESULTS

3.1 | Overall description

In Seattle, the 2021 EHE resulted in maximum daily temperatures of 102°F, 104°F, and 108°F from Saturday, June 26 to Monday, June 28, 2021, during which there were 909 ED visits and 247 inpatient admissions across the three area hospitals. The maximum daily temperatures during the reference period 3 weeks prior, from Saturday, June 5 to Monday, June 7, 2021, were 66°F, 55°F, and 64°F, and were associated with 888 ED visits, and 235 inpatient admissions, respectively. Of the total 2103 ED visits included in the analysis, the following exclusion criteria were applied: 57 visits were excluded due to patient aged <18 years, and 249 visits were excluded due to lack of classifiable diagnosis data.

Most patients included in the cohort were male (55%), White (66%), and publicly insured (63%), with a median age of 49 years (Table 1, Table S1). When compared to the reference period, patients in the index period were more likely to arrive by ambulance than other methods. There were no other statistically significant differences in patient characteristics between the two periods.

3.2 | Unadjusted excess ED visits and unplanned hospital admissions

Over the course of the EHE, there were 2% more ED visits than during the reference period 3 weeks prior. The largest increases in ED visits were associated with diagnoses of respiratory diseases excluding COVID (+19%), acute renal failure (+6%), and HRIs (+242%) (Table S2). HRI-related visits included electrolyte and fluid imbalance disorders (+82%), heatstroke/sunstroke (67 cases compared to none), and dehydration/volume depletion (+237%) (Table S2).

TABLE 1 Cohort description. All visits to emergency department (ED) during the 3-day extreme heat event and 3-day reference period occurring earlier in the same month by demographic and clinical characteristics.

	Reference period	Extreme heat event	Total
Total patients	888 (49.4)	909 (50.6)	1797 (100)
Age (median, IQR)	48 (33, 63)	49 (33, 66)	49 (33, 65)
Sex			
Female	382 (43.0)	429 (47.2)	811 (45.1)
Male	506 (57.0)	480 (52.8)	986 (54.9)
Race			
White	575 (64.8)	611 (67.2)	1186 (66)
Other race	313 (35.2)	298 (32.8)	611 (34.0)
Method of arrival			
Medic/aid/airlift	279 (31.4)	341 (37.5)	620 (34.5)
Car	486 (54.7)	437 (48.1)	923 (51.4)
Bus/walk	106 (11.9)	112 (12.3)	218 (12.1)
Other	17 (1.9)	19 (2.1)	36 (2)
ESI level			
Immediate	14 (1.6)	29 (3.2)	43 (2.4)
Emergent	243 (27.4)	267 (29.5)	510 (28.5)
Urgent	496 (55.9)	483 (53.4)	979 (54.6)
Less urgent	117 (13.2)	111 (12.3)	228 (12.7)
Non-urgent	17 (1.9)	15 (1.7)	32 (1.8)
Insurance			
Commercial	213 (24.0)	256 (28.2)	469 (26.1)
Medi-caid/Medicare	564 (63.5)	563 (61.9)	1127 (62.7)
Self-pay	72 (8.1)	63 (6.9)	135 (7.5)
Other	39 (4.4)	27 (3)	66 (3.7)
ED disposition			
Admit	235 (26.5)	247 (27.2)	482 (26.8)
Discharge	615 (69.3)	614 (67.5)	1229 (68.4)
Other	38 (4.3)	48 (5.3)	86 (4.8)
In-hospital mortality	14 (1.6)	9 (0.99)	23 (1.28)

Note: All data shown represent category frequency and percentage, unless otherwise specified.
Abbreviations: ESI, emergency severity index; IQR, interquartile range.

Hospital admissions were 5% higher during the EHE relative to the reference period, and greater for respiratory disease (+33%) and HRIs (+200%), with 22 hospitalizations versus zero prior (Table S3). However, none of the examined comorbidities (DM, cardiovascular disease, and renal disease) appeared to substantially contribute to increased hospital admissions (Table S3).

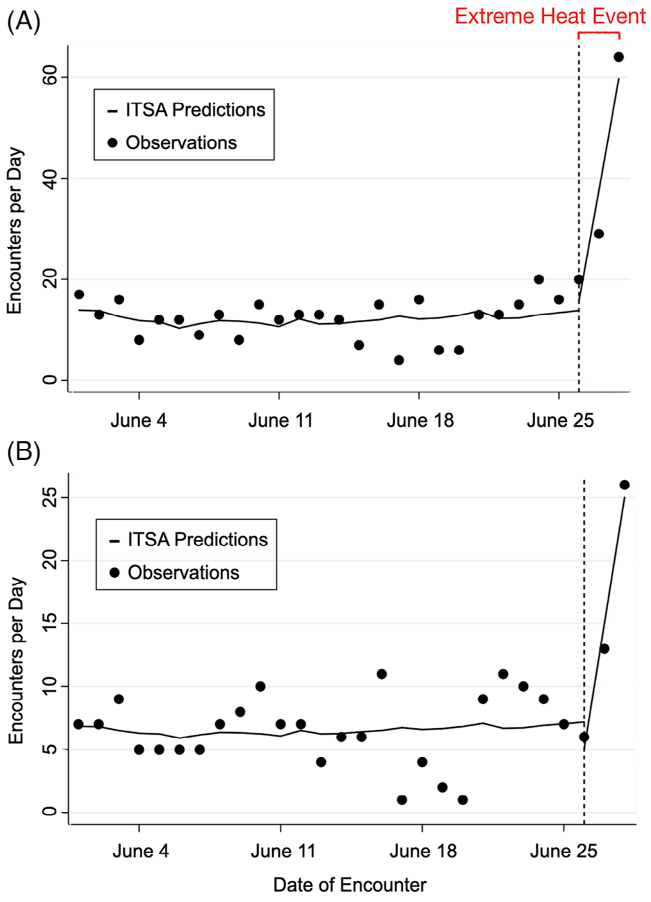

FIGURE 1 Line graph of interrupted time series analysis (ITSA)-predicted values for daily emergency department (ED) visits **(A)** and unplanned hospitalizations **(B)** related to heat-related illness in June across three hospitals, preceding and during the extreme heat event. Observed values are represented by solid circle markers.

3.3 | Heat-related illness during extreme heat event—interrupted time series analysis

During the month of June, preceding the heat dome event (June 1–25), daily maximum temperatures ranged from 55 to 89°F (interquartile range = 66, 79°F). To explore the effects of the EHE in the context of any underlying secular trends, we compared the affected dates to the preceding days in June via interrupted time series analysis (ITSA) with a lag of 0 days for ED visits (Figure 1A) and hospitalizations (Figure 1B) related to HRI. The EHE was associated with 21.7 (95% CI: 14.7, 28.6) additional model predicted ED encounters per day and 9.9 additional predicted admissions per day (95% CI: 8.3, 11.5). Observed daily maximum temperatures and associated HRI-related ED visit and admission volumes over 7 days surrounding the EHE are shown in Table S4; ITSA model coefficients and 95% CIs can be found in Table S5. No autocorrelation was detected in either model ($p = 0.16$; $p = 0.15$, respectively).

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TABLE 2 Covariate-adjusted risk factors for an emergency department (ED) visit associated with heat-related illness. The covariates presented below represent the totality of those included in the multivariable regression model.

	Incidence rate ratio	Lower 95% CI	Upper 95% CI
Heat dome period (vs. reference period)	3.19	2.16	4.71
Publicly insured (vs. not)	1.22	0.81	1.84
Female (vs. male)	1.47	1.06	2.04
White (vs. other race)	0.73	0.52	1.02
Age	1.02	1.01	1.03
Diagnosis of diabetes mellitus (vs. no)	3.19	1.47	6.94
Diagnosis of cardiovascular disease (vs. no)	0.97	0.55	1.70
Diagnosis of respiratory disease (vs. no)	1.16	0.65	2.10

Abbreviation: CI, confidence interval.

3.4 | Risk factors for HRI associated ED visits

The EHE resulted in an IRR of 3.19 (95% CI = 2.16, 4.71) for HRI-related ED visits compared to the reference period when adjusting for insurance status, sex, race, age, and previous diagnosis of DM, cardiovascular disease, and respiratory illness (Table 2). Patient characteristics positively associated with increased IRR of HRI were as follows: female sex (IRR = 1.47; 95% CI = 1.06, 2.04), older age (IRR = 1.02; 95% CI = 1.01,1.03), and DM (IRR = 3.19; 95% CI = 1.47, 6.94).

3.5 | Effects on ED workflow

Repeat ED visits within 48-h of the initial visit were significantly higher during the heat event with a rate of 4.9% (95% CI: 3.6, 6.1) compared to the reference period with a rate of 2.0% (95% CI: 1.1, 2.9).

Hourly occupancy rates and EDWIN scores in the EHE relative to the reference period showed site-specific patterns (Figures 2 and 3). Overall, occupancy rates were similar on days 1–2 of the EHE and reference period, but were significantly higher during the EHE on day 3 (average occupancy rate = 1.8; 95% CI = 1.7, 1.9), compared to the reference period (average occupancy rate = 1.4; 95% CI = 1.3, 1.5). Similar patterns were observed with EDWIN scores for which higher scores indicate increased ED crowding, with a significantly higher average EDWIN score during the EHE (EDWIN = 3.5; 95% CI: 3.3, 3.8) on day 3 versus the reference period (EDWIN = 2.6; 95% CI = 2.4, 2.8).

ED throughput times also increased over the 3-day heat event, with differences becoming most pronounced by day 3, culminating into an additional 0.3 h (95% CI: 0.2, 0.5) from patient arrival to being roomed in the ED, an additional 0.3 h (95% CI: 0.2, 0.5) from arrival to being first seen by an ED provider, and an additional 1 h (95% CI: 0.4, 1.6) for total ED length of stay compared to the reference period.

3.6 | Limitations

This study has several limitations. Although in-hospital mortality data were available, no linkage was performed with death certificate data to compare to community or out-of-hospital mortality. This analysis also focused on only three of the numerous regional hospitals and associated EDs, so there may be limitations to drawing conclusions to apply to the greater Seattle area. Additionally, this analysis was conducted in a single urban area with a unique, tiered emergency medical services (EMS) system that provides exceptional care and consistently demonstrates high rates of survival from out-of-hospital cardiac arrest which may limit generalizability to other regions.[21,22] Regarding the statistical methodology, the cause-specific HRI admissions were limited by low sample size, with less than 10 patients for many specific diagnoses. Pediatric patients were also excluded from this analysis due to low sample size. Finally, power analysis suggests that detecting differences in mortality between the periods would require 5781 subjects, a volume of patients not observed in this analysis.

4 | DISCUSSION

4.1 | Summary of findings

This analysis illustrates the burden experienced by three Seattle-area EDs during the unprecedented heat dome of 2021. Compared to the reference period, there was a significant increase in all-cause ED visits and unplanned hospitalizations. Cause-specific ED visits and hospitalizations increased for respiratory disease, acute renal failure, and HRI. No significant difference was observed for in-hospital mortality between the heat dome period and the reference period, although the study was underpowered to detect a difference. No significant differences were observed in patient characteristics between the heat dome and reference period, although patients in the EHE were more likely to arrive by ambulance, suggesting an increased illness acuity. Increased ED crowding and length-of-stay were also observed during the heat dome period.

4.2 | Biological mechanisms

Heat illness results when the natural thermoregulatory mechanisms are overwhelmed.[3] Beyond the spectrum of heat illness, exacerbations of cardiorespiratory disease, renal disease, and psychiatric illness have been observed.[2] Multiple medication classes, including diuretics and psychotropics, can impede thermoregulation in heat exposure.[3]

The findings in this analysis are consistent with these known mechanisms of HRI and other evaluations of the same EHE.[7,8,10] Increased ED visits and hospitalizations associated with electrolyte derangements

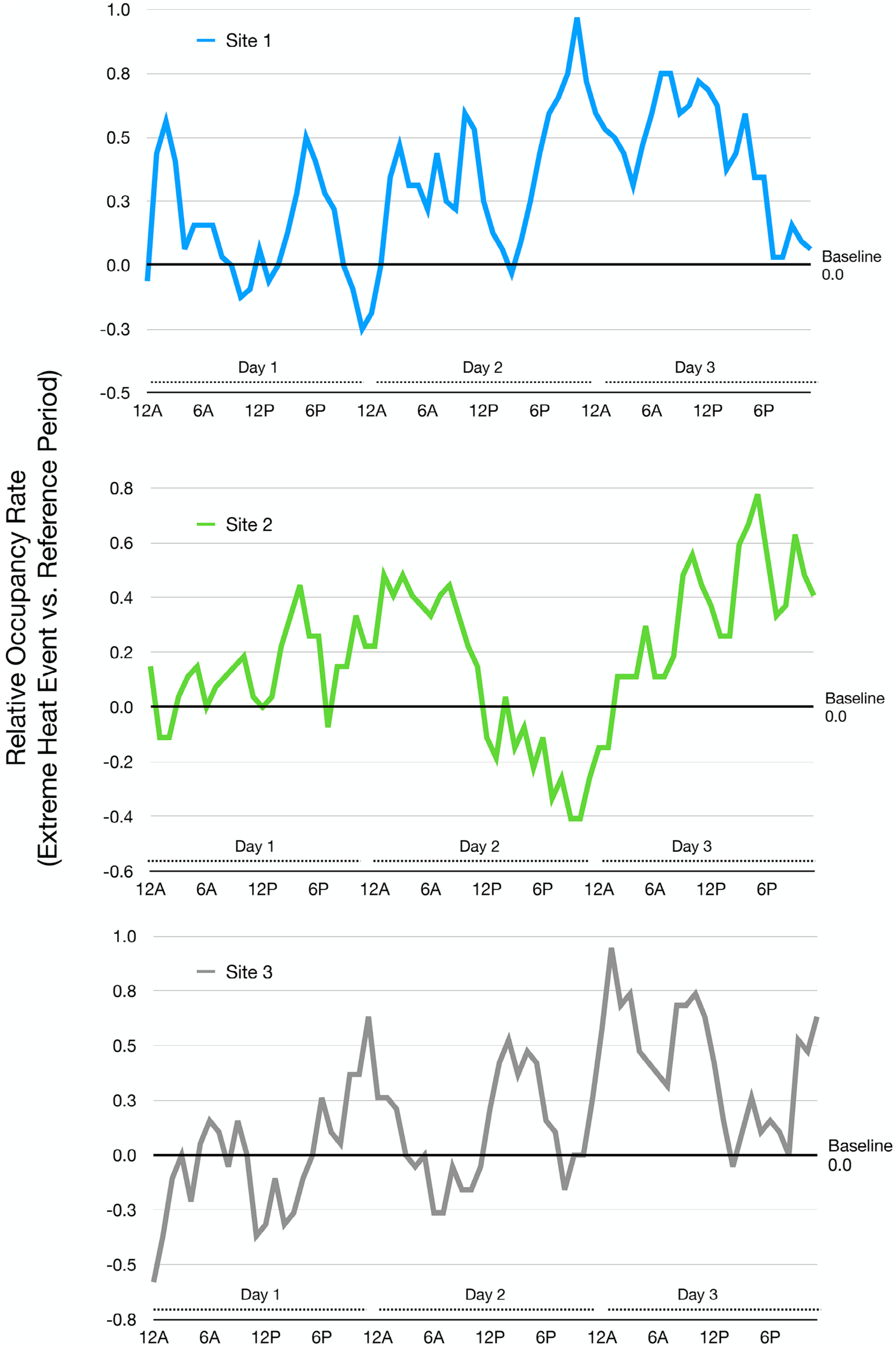

FIGURE 2 Relative occupancy rates across three hospitals during the heat dome period compared to the reference period.

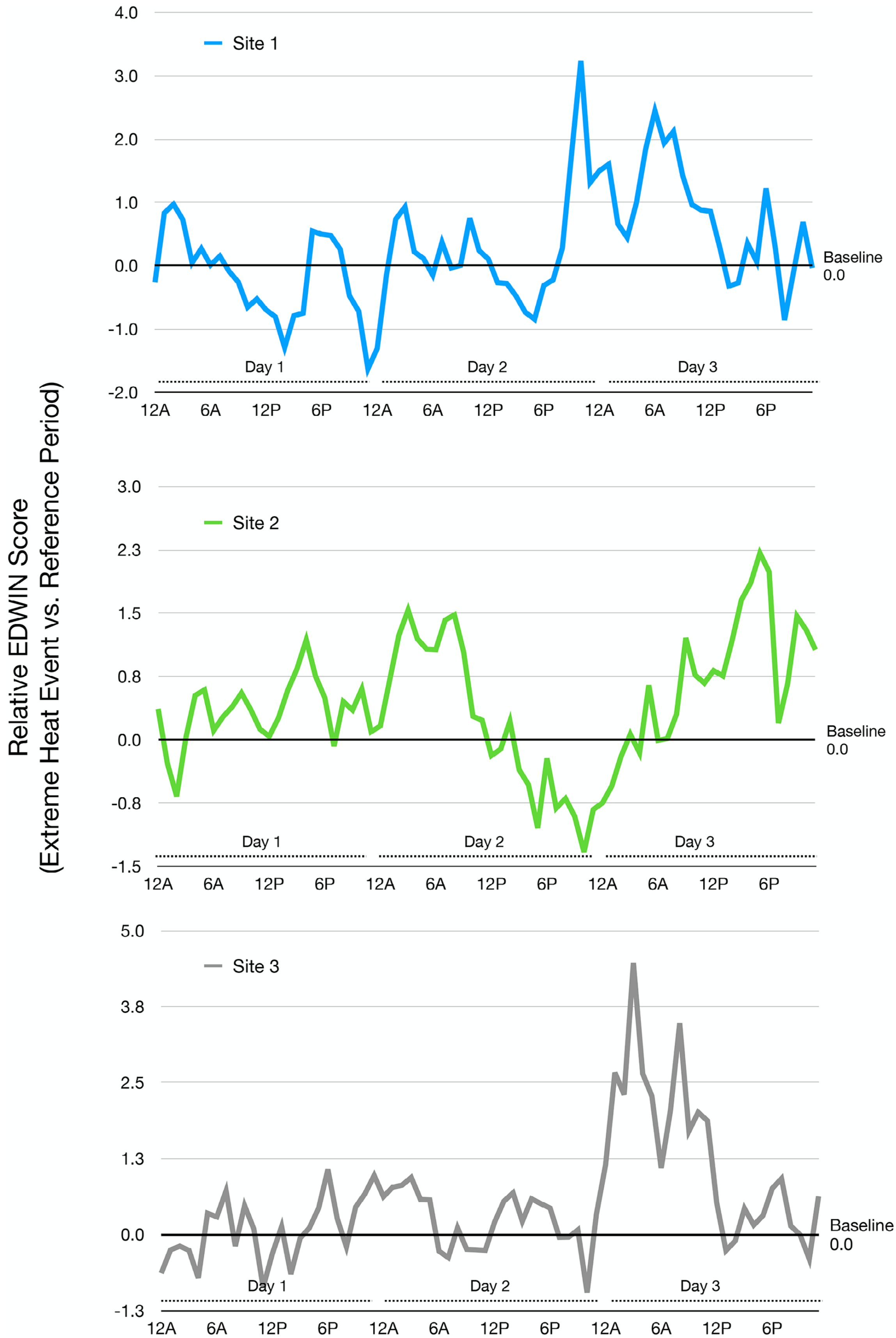

FIGURE 3 Relative ED Work Index Score (EDWIN) scores across three hospitals during the heat dome period compared to the reference period.

and dehydration are known consequences of heat exposure and similarly, respiratory distress and failure can be observed in the context of heat stroke. The increased hospitalization volumes and increased ambulance use for ED arrival suggest a higher acuity patient volume. Interestingly, no significant difference was observed for in-hospital mortality, despite the known mortality risk associated with heat stroke, although this analysis was not powered to detect a difference. Comparable regional estimates of mortality are not available, but state-level estimates range from 100 to over 400 deaths due to the EHE depending on the definitions and time period used.[9,23,24]

4.3 | Vulnerable populations

In this analysis, risk factors for ED visits during the EHE were female sex, increased age, and history of DM. These findings are consistent with previous literature documenting risk factors for HRI.[2,3]

Beyond clinical risk factors for HRI, prior work has demonstrated socioeconomic and community-level risk factors.[2,3] A heat-mapping project from the City of Seattle and King County demonstrated inequitable heat exposure with higher temperatures, persisting for longer, in urbanized neighborhoods with less tree cover.[25] These regions also coincided with other predictors of comorbid conditions and decreased socioeconomic status. In the Seattle-area, where air conditioning use is less prevalent than in other regions of the United States, community-level factors may play a significant role in regional differences in heat exposure.[8] Prior work has shown a disproportionate exposure to heat in urban environments experienced by minority and disadvantaged communities related to historical racial segregation and historically racist structural practices such as Redlining.[26–29]

4.4 | System impacts and preparedness

This study found increased ED volumes, return visits, prolonged length-of-stay, and work index scores associated with the heat dome.[30] Heat has been associated with increased EMS utilization, ED arrivals and length of stay, and mortality.[31–34] Similar findings have been published elsewhere and indicate the impacts not only on patient volumes but on ED throughput and function during these events. As communities implement early warning systems and heat action plans for extreme heat events, hospital systems need to be similarly prepared for patient surges, staffing shortages, and disruptions in critical utilities and supplies.[2,35–37] As reported in a regional emergency medicine conference on local ED experiences during the 2021 EHE, shortages of ventilators were experienced due to the high volume of patients experiencing respiratory failure, and there was extensive coordination between facilities to load balance high acuity ambulance traffic to EDs experiencing less demand.[38,39] As the world continues to warm under anthropogenic climate change, the rate of EHEs will increase disproportionately, and the need for additional preparedness is clear.[40]

There is relatively limited literature on strategies for increasing preparedness for extreme heat in healthcare delivery systems. Best practices recommend close coordination and linkage between extreme heat emergency preparedness and longer term risk reduction efforts, which are often coordinated by state and local health departments.[2] Health care delivery systems can take a number of additional steps to increase preparedness and maintain continuity of operations during extreme heat events.[41,42] Priorities include conducting climate risks and vulnerability assessments in collaboration with local health and emergency preparedness authorities and community partners; planning for essential clinical care and services delivery, including provider training and development of communications plans; and infrastructure protection and resilience planning, including development of mutual aid strategies to maintain continuity of service and disaster planning.[42] Resilience planning should also include stress testing using disaster planning scenarios updated with single- and compound-hazard information informed by climate change projections.[43,44] Resilience planning also includes alignment of health system operations with carbon neutrality goals, an important form of primary prevention, harm reduction, and strategy for energy resilience.[45–47]

In summary, the heat dome of 2021 contributed to a measurable increase in ED visits and hospitalizations for a range of conditions across three University of Washington Health System hospitals. These findings were consistent with prior studies demonstrating a direct contribution toward HRI, as well as renal injury and respiratory disease outcomes. Beyond patient health impacts, the EHE demonstrated impacts on ED workflow, with increased rates of return visits, prolonged length of stay, ED occupancy rate, and work index scores. Additional reporting has highlighted the dramatic regional increase in emergency care demand and the potential for extreme heat to precipitate mass casualty events that can put healthcare facilities in crisis.[7,48] As the risk of extreme heat events are projected to increase in frequency and intensity with climate change, ED preparedness for these events is essential for maintaining proper standard of care during these trying periods. Further investigations are warranted to explore ED impacts on a regional scale, as well as identification of vulnerable populations and interventions to reduce impacts on healthcare delivery and system functioning.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization of the study. Jane Hall performed the statistical analysis and model development. Cameron Buck and Steven H. Mitchell contributed to health records data acquisition. Zachary S. Wettstein, Jane Hall, and Jeremy J. Hess wrote the first draft of the manuscript, and all the authors provided substantive feedback and review.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

This study utilized protected health information and can be shared when a data sharing agreement is in place with the University of Washington.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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