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Research article

Trends in heat related illness: Nationwide observational cohort at the US department of veteran affairs☆

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ABSTRACT

Introduction: Environmental heat can have a negative impact on health, leading to increased healthcare utilization, disability, and death. Specific clinical conditions, in combination with a global rise in temperature, may amplify the risk of heat related illnesses.
Materials and Methods: We conducted a retrospective analysis of VA's national electronic health record database from January 1, 2002, through December 31, 2019. Heat related illness diagnoses were assessed for associations with patient demographics, comorbidities, and geographic residence at the time of a heat related illness diagnosis. Descriptive statistics, linear regression, and additive seasonal decomposition methods were utilized to assess risk factors and trends.
Results: There were 33,114 documented cases of heat related illness, which impacted 28,039 unique patients, during our 18 year assessment period. Veterans were diagnosed with heat related illnesses in all 50 US states and there was an increase in the rate over time. The likelihood of heat related illnesses was greater for those with increased comorbidity burden. Rates increased for homeless Veterans in the first half of the assessment period, and then declined for the second half. Black, as well as American Indian/Alaska Native Veterans accounted for a greater proportion of heat related illnesses.
Conclusion: There has been a statistically significant and clinically important increase in the incidence of heat related illnesses over time. There has also been an increased number of heat related diagnoses associated with existing health and demographic factors, and the increase over time did not strictly follow the expected geographic North-South climate trends.

1. Introduction

According to the Centers For Disease Control and Prevention (CDC), from 2004 to 2018, there were an average of 702 documented heat related deaths, 67,512 emergency department (ED) visits, and 9235 hospitalizations reported each year in the United States (US) [1,2]. However, these are likely underestimates as data on heat related illnesses (HRI) and death are not comprehensively captured or reported [3]. Additionally, global average temperatures have been increasing. In the US, the annual average temperature increased by 1.2°F from 1986 to 2016, and is expected to accelerate, with an additional 2.5°F increase projected for the period from 2021 to 2050 [4]. Climate projections indicate that extreme heat events will be more frequent and intense in the coming decades [5]. Although anyone can suffer from HRIs, the most susceptible include those with existing medical conditions, lower income, homeless, those who work outdoors or in areas without air conditioning, as well as the very young and old [6].

1.1. Healthcare system context

The US Department of Veterans Affairs (VA) provides comprehensive healthcare services through the Veterans Health Administration

☆ The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention or the US Department of Veterans Affairs.

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(VHA). The VHA is the largest integrated healthcare system in the US, with 1298 facilities located across the US serving over 9 million enrolled Veterans [7]. Enrolled Veterans represent a diverse population, who are older, have a greater likelihood of multiple comorbidities and disability, lower income, and are more likely to work outdoors or in areas without air conditioning [8–10]. Equitable high-quality health care and prevention is a cornerstone of VHA's mission, and part of this goal involves proactively identifying health risks, as well as potential disparities, which are important for optimizing care and prevention approaches.

1.2. Summary of aims

This VHA population-level assessment was designed to focus on four areas of HRI: 1) quantify the incidence of HRI over time; 2) assess the temporal trends of HRI in relationship to geographic locations; 3) evaluate the impact and trends of HRI for different patient populations, and 4) the intent of this work is that it will contribute to and inform ongoing efforts designed to enhance care for all Veterans, as well as to proactively identify those patients and communities who would benefit the most from data informed strategic heat mitigation interventions.

2. Materials and methods

2.1. Patients

We conducted a longitudinal retrospective analysis of routinely collected patient data from the VHA's national electronic health record (EHR) database, the Corporate Data Warehouse (CDW). The CDW is a relational database that aggregates medical and administrative records from all VA facilities. CDW tables related to diagnosis, admissions, and ED visit information were queried to identify HRI's diagnosed from January 1, 2002, through December 31, 2019. Patient HRI data were obtained from both structured International Classification of Diseases, 9th (ICD-9) and 10th (ICD-10) revision diagnostic codes (S1), as well as from unstructured data. The unstructured data were obtained by searching for keywords related to HRI in the ED visit chief complaint field and admission reason text fields (S2). To prevent overcounting, only one HRI event was counted per patient, per unique episode of care. A unique episode of care was defined as a patient presenting with an acute HRI to a VHA facility regardless of disposition. For example, a patient that presented with an HRI, and was subsequently admitted for multiple sequential days, was only counted one time. We only included VHA care and did not capture records of Veteran care at non-VA facilities due to incompleteness and variability of records available from different non-VHA institutions. To assess the proportional impact for VHA patients, the total number of Veterans enrolled each year, and at each facility, was utilized and obtained from the VHA Allocation Resource Center (ARC) via VHA Support Service Center (VSSC) [11,12]. Data from 2020 to date were not included in the assessment to eliminate the expected confounding factors associated with the COVID-19 pandemic, such as the fluctuating and heterogenous multifactorial time-varying clinical care disruptions and policy changes during this time [13–16].

2.2. Patient variables

To assess at-risk groups, that may be disproportionately impacted by HRIs, we assessed patient demographic and health status information at the time of the HRI diagnosis. We also utilized the Charlson Comorbidity Index (CCI) without age as a proxy for individual patient comorbidity burden. The CCI is based on whole number calculation, with the severity categorized into three grades; mild 1–2, moderate 3–4, and severe ≥5 [17]. We defined each condition in the CCI from diagnosis codes retrieved from health care encounters per the calculation from Quan et al. [18]. Common comorbid conditions were also separately assessed, including congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), diabetes-mellitus (DM), and hypertension (HTN). Additional variables were included in the evaluation such as patient geographic residence, documented positive homelessness screen within two years prior to HRI diagnosis, age, race, and ethnicity. Table 1

2.3. Analysis

HRI incidence was calculated monthly over the assessment period. To adjust for seasonal trends, we applied additive seasonal decomposition, using moving averages [19]. We calculated the rate of HRI per 100,000 VHA enrolled patients, per year (Table 2). Using linear regression, we plotted the incidence of HRI for each month during the 18-year assessment period.

At an enterprise health administration level, the VHA updated the primary medical coding system from ICD-9 to ICD-10 on October 1, 2015. To control for the potential effect that this coding system change may have on data, we calculated the slope change of HRI for three separate time-periods: the overall trend for the entire time period (January 2002-December 2019), the ICD-9 time period (January 2002-September 2015), and the ICD-10 time period (October 2015-December 2019).

To further understand the incidence of HRI for specific populations, we quantified and assessed key demographic and health related variables. These data were also converted to an average for each year in our dataset and plotted over the evaluation timeframe to assess potential temporal trends.

Our dataset contains HRI data from all 50 US states and the District of Columbia. We applied a linear regression model to the incidence of HRI, by month, to calculate the slope change for each state during the assessment timeframe. The statistical analyses were performed using Python 3.7 and Microsoft Excel.

Table 1
Patient Characteristics.

Patient Information	
n =	33,114
Age (Mean) (SD)	58.9 (16.1)
Male (%)	30,681 (92.3)
Charlson Comorbidity Index (CCI) Information	
CCI Average (Range)	2.4 (0–23)
No Comorbidities (0) (%)	10,398 (31.4)
Mild (1–2) (%)	10,909 (32.9)
Moderate (3–4) (%)	5839 (17.6)
Severe (5+) (%)	5968 (18.0)
Condition-Specific Elements	
Hypertension (%)	21,295 (64.3)
COPD (%)	11,800 (35.6)
CHF (%)	4203 (12.7)
Diabetes (%)	9800 (29.6)
Race	
AMERICAN INDIAN OR ALASKA NATIVE (%)	362 (1.1)
ASIAN (%)	178 (0.5)
BLACK OR AFRICAN AMERICAN (%)	6997 (21.1)
NATIVE AMERICAN OR OTHER PACIFIC ISLANDER (%)	275 (0.8)
NOT REPORTED (%)	3527 (10.7)
WHITE (%)	21,805 (65.8)
Ethnicity	
HISPANIC OR LATINO	1275 (3.9)
NOT HISPANIC OR LATINO	25,080 (75.7)
NOT REPORTED OR UNKNOWN	6789 (20.5)

Table 2
Vol of HRI diagnoses, VA enrollment, and HRI diagnoses per 100,000 enrolled Veterans, per year.

Year:	2002	2003	2004	2005	2006	2007	2008	2009	2010
# of Dx:	1531	1279	1046	1386	1412	1159	1082	1078	1575
Enrollment:	6,480,231	6,930,418	6,866,295	7,455,757	7,651,954	7,557,552	7,689,619	7,767,762	7,994,771
Per 100k:	23.6	18.5	15.2	18.6	18.5	15.3	14.1	13.9	19.7
Year:	2011	2012	2013	2014	2015	2016	2017	2018	2019
# of Dx:	2120	1930	1554	1255	1954	3471	2897	3208	3177
Enrollment:	8,526,348	8,683,937	8,782,249	8,659,320	8,843,688	8,970,374	9,045,868	9,124,916	9,150,831
Per 100k:	24.9	22.2	17.7	14.5	22.1	38.7	32.0	35.2	34.7

2.4. Ethics

This quality assessment project received determination of non-research from Stanford IRB (Stanford University, Stanford, CA, USA) #62,150.

3. Results

3.1. Patient characteristics

We identified 33,114 reported cases of HRI, which impacted 28,039 unique patients, during our 18-year assessment period. 2781 (8.4%) of HRI cases were captured in unstructured fields, such as the ED chief complaint or admission reason, and did not have a corresponding ICD9 or ICD10 diagnosis. The remainder of the HRI cases were identified with ICD9 and ICD10 codes from the EHR database. The average age of impacted patients was 59 years. The average CCI for the population was 2.4. Nearly 65% of patients had a HTN diagnosis; 36% had a COPD diagnosis; 30% had a DM diagnosis, and nearly 13% had a CHF diagnosis at the time of their HRI diagnosis (Table 1).

Black and American Indian/Alaska Native Veterans were more likely to be diagnosed with HRI. Black Veterans accounted for 21.1% of all HRI diagnoses, which is greater than the overall Black VHA population enrollment of 15.5%. In contrast, White Veterans made up 65.8% of all HRIs, which is less than their overall VHA enrollment of 72.9%. American Indian/Alaska Native Veterans had 1.1% of the HRI

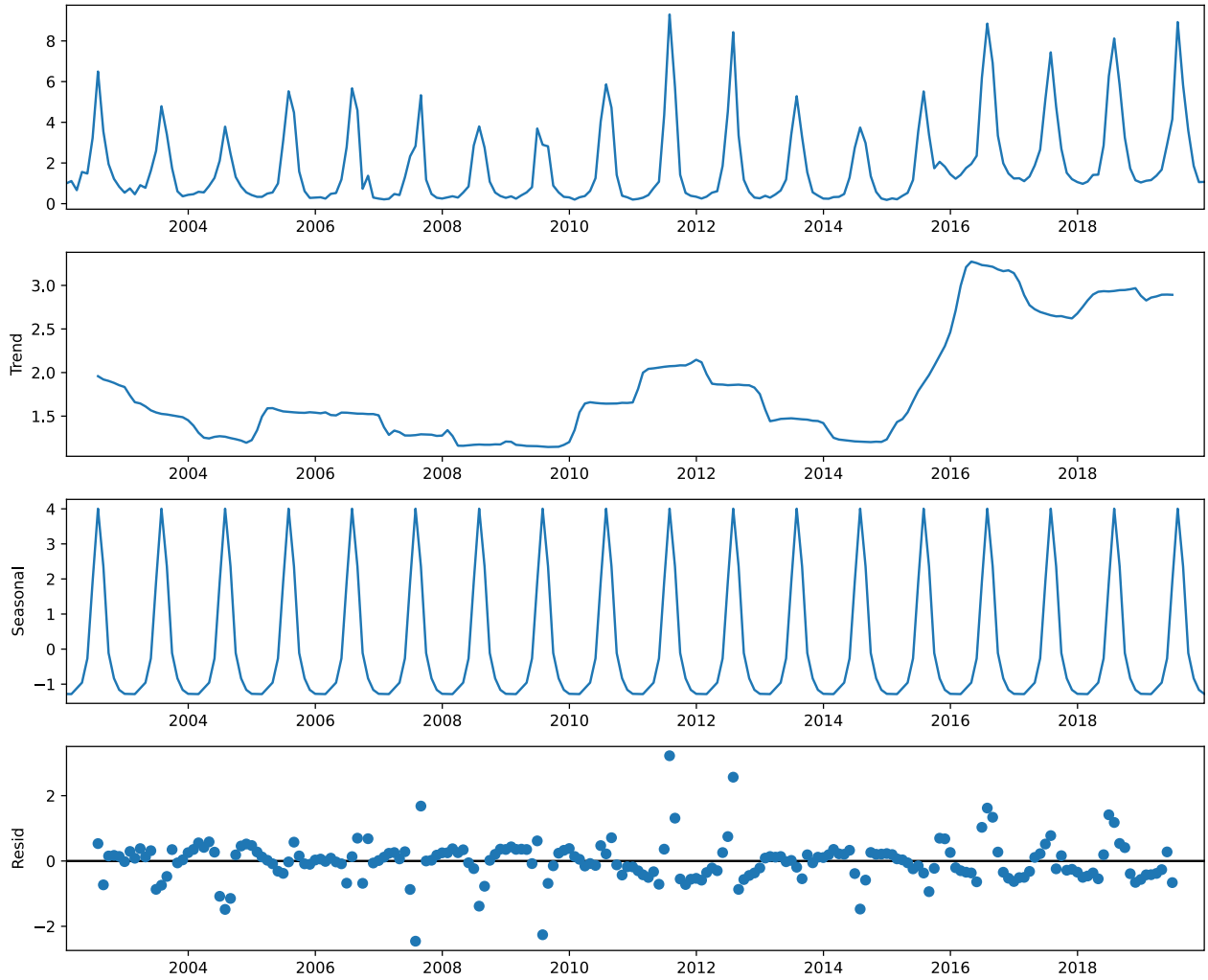

Fig. 1. A & B HRI diagnoses per 100,000 enrolled Veterans between January 1, 2002 through December 31, 2019, plotted by day (A) and by trend which utilizes seasonal decomposition, using a moving average of volume of diagnoses over time (B).

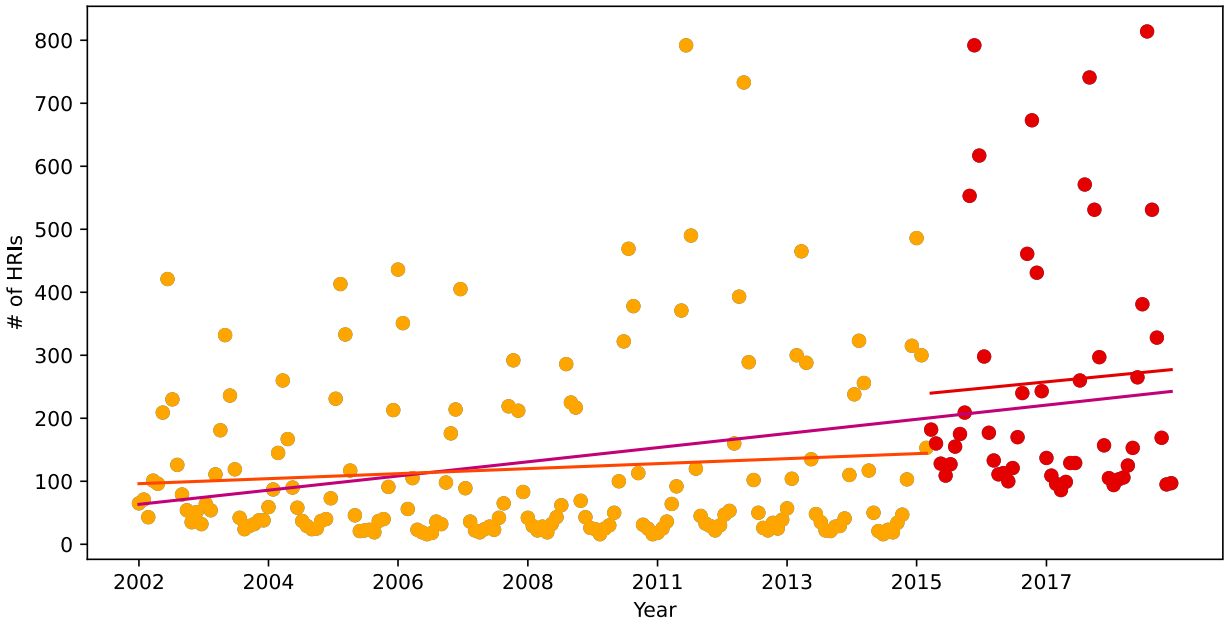

Fig. 2. Incidence of HRIs by month, with trend line fitted for entire 18 year period (January 2002-December 2019). The ICD-9 period (January 2002-September 2015), and the ICD-10 period (October 2015-December 2019) trend lines are also demonstrated.

diagnoses, compared to their total VHA enrollment of 0.6%. Asian Veterans accounted for 0.5% of HRI diagnoses, compared to their total VHA enrollment of 0.6%. Hispanic or Latino Veterans made up 3.9% of HRI parents compared to the overall VHA enrollment of 5.4% [20,21]. This higher risk of HRI in specific demographics aligns with previous research showing American Indian/Alaska Natives and non-Hispanic Blacks had the highest rates of heat-related deaths [2].

3.2. Incidence of HRIs

Overall temporal trends of HRI's were plotted as the incidence per 100,000 patients based on yearly enrollment. Trends demonstrated significant and predictable seasonal variability, with regular annual spikes during the summer months (Fig. 1a). After adjusting for seasonal variability, the incidence of HRI's demonstrated an overall increase over time (Figs. 1b, 2, and Table 2). The most significant apparent focal increase in HRI's was observed at the end of 2015, which also coincided with the transition from ICD-9 to ICD-10 across VHA. To account for the potential artifact related to changes in data collection methods, we fit linear regression lines to each separate time period (ICD-9 & ICD-10), both of which continued to demonstrate a positive slope (increase in HRI) during each independent time-period, with the ICD-10 timeframe showing overall higher values. (Fig. 2) (Table 3).

3.3. Impact of comorbidities, homelessness, and age

The subpopulation of patients with multiple comorbidities, leading to a CCI classification of moderate, and severe, had a steadily increased rate of HRIs (from -10% in 2002 to -25% in 2019). In contrast, the subpopulation with none of the CCI comorbidities, or classified as mild CCI, had a decreasing trend of HRI's over the assessment period (~39% in 2002 down to -28% in 2019) (Fig. 3).

Furthermore, the incidence of patients with HRI, and each of the common chronic conditions we assessed, had increased over time. Patients having CHF and HRI increased from ~10% in 2002 to around 15% in 2019, a 50% increase. The same trend was observed for other major chronic conditions; COPD (25% to 40%), DM (24% to 35%), and HTN (50% to 70%). However, the correlation of HRI and homelessness steadily increased from 2002 to a peak in 2014 followed by a steady decline from 2015 to 2019. The association of patients average age and diagnosis of HRI has stayed relatively consistent over the total assessment period, with the average ranging from 56 to 62 years of age. (Fig. 4)

Table 3
HRI/month slope change for each assessment period; for all (January 2002-December 2019), ICD-9 (January 2002-September 2015), and ICD-10 (October 2015-December 2019).

Slope Change		95% CI
ICD-9 (2002-Sep 2015):	0.01	−0.005 – 0.025
ICD-10 (Oct 2015–2019):	0.024	−0.106 – 0.155
Overall:	0.027	0.016 – 0.039

3.4. Temporal impact of geographic residence

There has been an increase in diagnosed HRIs among Veterans for nearly all US states during our assessment period with a disproportionate increase in HRIs most notably in California, Florida, and Texas. There were also notable increases in HRI diagnoses in other states such as Missouri, Arkansas, Virginia, Ohio, and New York (Fig. 5, and table S3). In contrast, Utah, New Mexico, Wisconsin, and most states in New England did not see as dramatic of an increase to their overall HRI diagnoses over the assessment period. However, Wisconsin was the only US state that saw a decrease in HRI, which was nominal. The table of diagnosed HRIs for each state, over 18 years, is provided in the supplementary information along with slope of change overtime for each US state (S3). The slope of HRI change for each state, over the assessment period, is visualized in the corresponding heat-map of the US (Fig. 5).

4. Discussion

An important observation from this assessment is that there has been a statistically significant and clinically important increase in HRI's over the assessment period, and that all US states are susceptible to HRI. However, the distribution of HRI incidence across the US was unexpected, revealing that the increasing risk was not

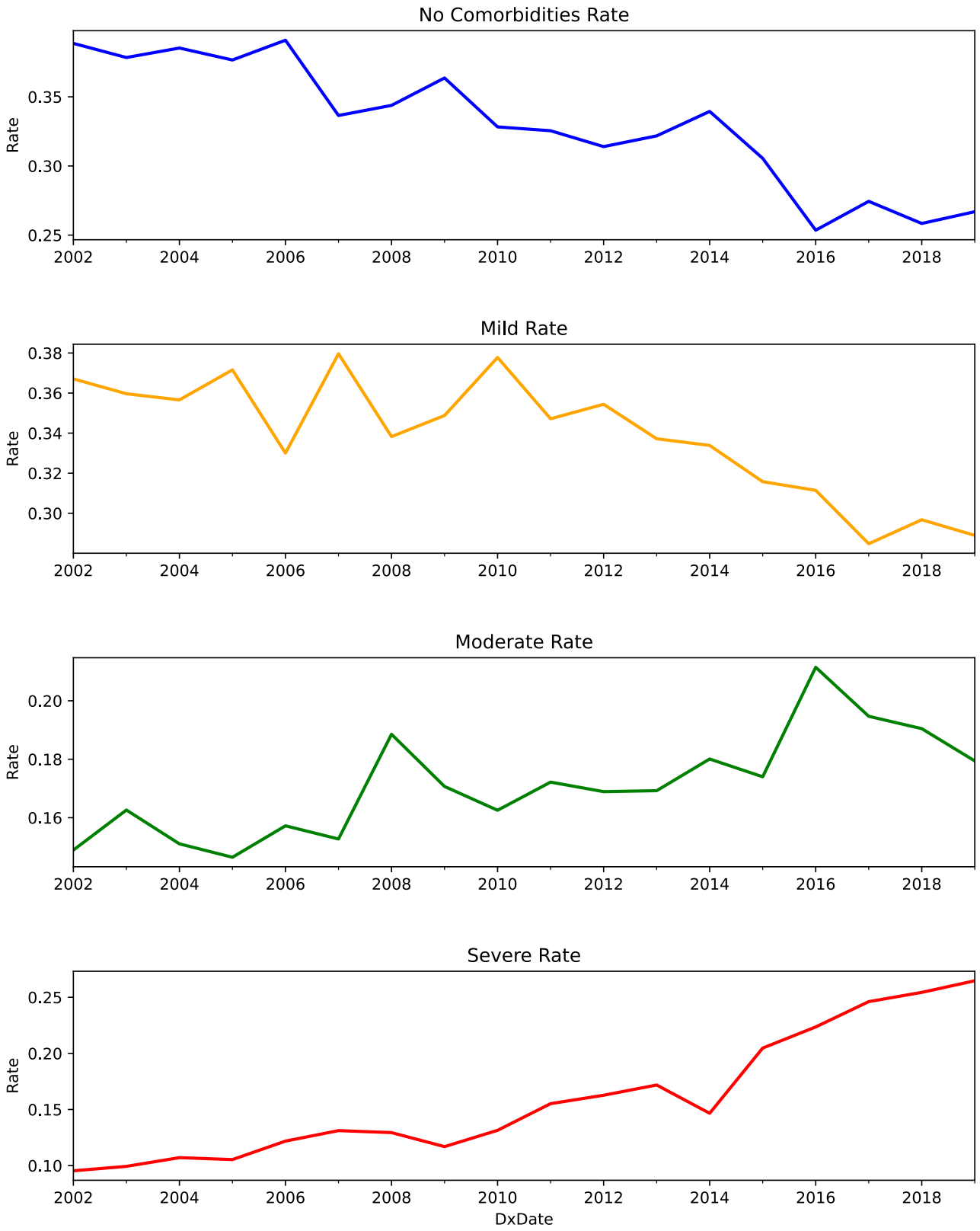

Fig. 3. The proportion of total HRI diagnoses based on Charlson Comorbidity Index (CCI) severity grade.

strictly confined to latitude. For example, there were notable increases in HRI diagnoses in Missouri, Arkansas, Virginia, Ohio, and New York, however, some typically warmer US states, such as New Mexico, Nevada, Utah, and Louisiana, did not have a dramatic increase in their overall HRI diagnoses over the assessment period. One potential explanation for this observation is that people and programs in these traditionally warmer US states have already adopted policies, procedures, and practices that effectively mitigate the negative health consequences of environmental heat. However, some locations, that do not traditionally or as commonly

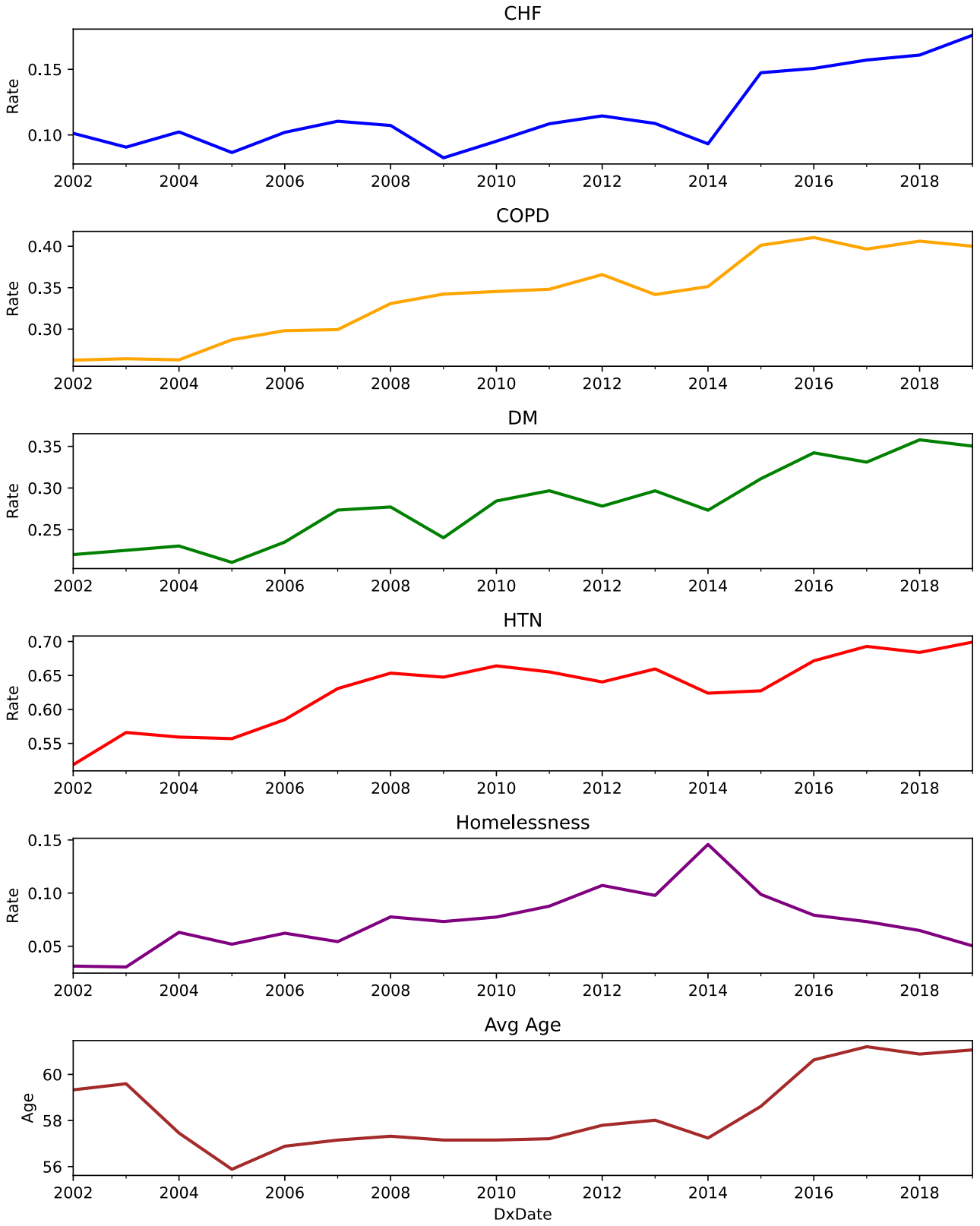

Fig. 4. Rate of common chronic conditions, homelessness and average age for Veterans diagnosed with HRIs over our assessment period. *Congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), diabetes-mellitus (DM), and hypertension (HTN).

experience hot weather, may not be as prepared during an extreme heat event.

Our evaluation also revealed significant insights about our most at risk patients. The risk of HRI had disproportionally increased for patients with underlying health conditions, as measured by moderate and high CCI scores. Similarly, the incidence of HRI in association with common chronic conditions, also steadily increased over the 18-year timeframe. Conversely, the cohort of healthier patients, as determined by mild CCI scores and/or lack of co-morbidities, resulted in a trend of less HRIs over the assessment timeframe.

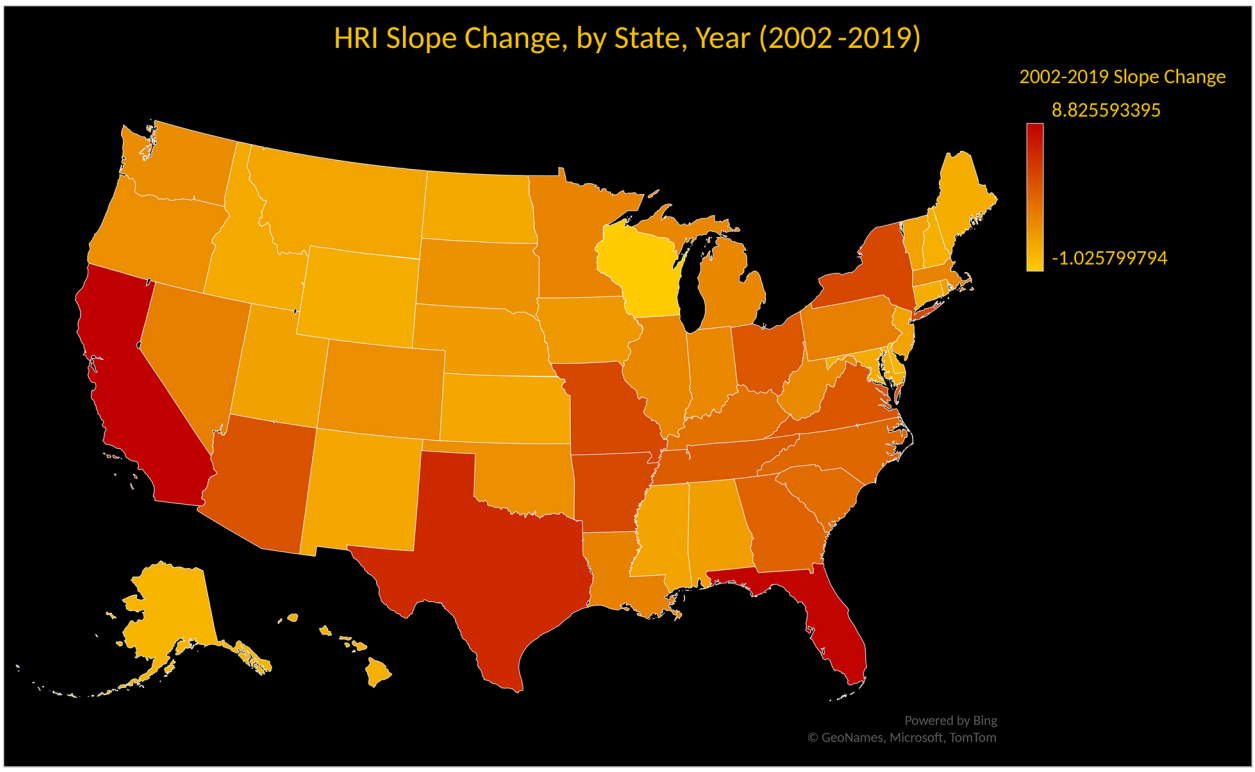

Fig. 5. Heat map of all 50 US states and District of Columbia. Color density corresponds with slope change of HRI diagnoses over our assessment period (Table S1) (red = larger positive slope, followed by orange, and the least slope change in yellow).

Interestingly, our results show that the rate of HRI in our homeless Veteran population had been increasing, but then turned around and decreased over the last half of the assessment timeframe. Although these homeless trends in HRI are statistically and clinically significant, our data does not identify a specific cause. However, we conjecture that the results may be related to Veteran homeless health and wellness programs being initiated, and expanded upon, during this timeframe of increasing environmental temperatures [22–25].

Our unadjusted data revealed that there were significantly more White Veterans diagnosed with HRIs. However, the proportion of White Veterans with HRI, compared to the total VHA enrollment, was significantly less than other race groups. The converse relationship was observed for Black, and American Indian or Alaskan Native Veterans, who our data demonstrated are more likely to be diagnosed with HRI. Asian Veterans rate of HRI was roughly proportional to their total enrollment and Hispanic Veterans had less HRI diagnoses in proportion to their total VHA enrollment. While VHA lowers barriers to healthcare access for Veterans, our findings suggest that some groups of Veterans are not immune to the negative external effects of HRI as it relates to social determinants of health factors such as race. This information provides important areas for additional targeted assessment and quality improvement intervention.

A major strength of this work is that it represents a longitudinal nation-wide assessment from the largest integrated healthcare system in the US. The considerable amount of data revealed statistically significant insights which allowed us to both quantify temporal and geographic trends as well as reveal unexpected insights. To our knowledge, this is the largest assessment of HRI using patient-level data, and the first at VA.

A novel strength of our assessment is that in the process of assessing this data, we also uncovered an important potential pitfall and solution for other investigators. In our healthcare system, the coordinated and enterprise-wide transition from ICD-9 to ICD-10 coding classification was associated with an apparent sudden, and rapid increase in the documented incidence of HRIs. Although coding changes from ICD-9 to ICD-10 have been observed to create spurious apparent changes in recorded disease frequency for other conditions, this is the first known description in the setting of HRI [26,27]. We accounted for this coding transition date by separately assessing the ICD-9 and ICD-10 timeframes, and in doing so, we were able to demonstrate a difference but also a persistent increase in documented HRIs for both time periods, with a greater number and greater slope during the current ICD-10 time period.

Veterans have the option to receive care at other healthcare systems and have been empowered to obtain supplementary or alternative care outside VA with several notable initiatives, including laws such as the Choice Act of 2014, and the Mission Act of 2018 [28,29]. Because of inconsistencies in data collection and availability of data from care received outside of VHA, we did not include data about Veteran care provided outside of VHA. Although this approach increases the reliability of the available data, this is also a limitation that not only results in an undercounting of the total numbers of HRIs, but would also artificially blunt the trend of increased HRIs over time. As a result, it is likely that the real incidence of HRIs, as well as the increase in cases over time, is greater than this assessment is able to reveal.

Finally, this assessment may have limited generalizability as our evaluation is focused on understanding and improving the care for our unique Veteran population, who are on average more likely to be male, have a greater likelihood of comorbidities as well as a predisposition for specific clinical conditions, are likely to be older, and have more socioeconomic challenges compared to the general US population [8–10]. However, some of these discrepancies may narrow in the future as the general US population continues to age and the incidence of comorbidities increases for the rest of the country.

There are important areas to consider for future work. For example, there are additional variables worth assessing, including specific medications such as beta-blockers, diuretics, and calcium-channel blockers, that alone, or in combination with existing comorbidities, may interfere with thermoregulation and hydration thereby having the potential to increase the risk of HRI [30]. Furthermore, excessive

alcohol use, other drug abuse, as well as associated mental health conditions could exacerbate and/or be exacerbated by excessive heat exposure [31]. A variety of other clinical conditions, such as renal disease with or without dialysis, obesity, and gout are also worth assessing as additional risk factors in future assessments [32–36]. In addition, there have also been recent reports suggesting that exposure to high temperatures in earlier life may increase susceptibility to HRI in later life [37]. Therefore, future work that assesses the consequences of potential high temperature events during a patient's younger years, such as during military service, may help to better identify individuals at greater risk for HRI. Further understanding and visualization of the impact of heat islands, as well as county-level social determinants of health [38], and the temporal relationship of HRI to specific changes in local temperatures is of great interest. The weighted combination of these types of factors, and their complex relationships, may contribute to operationally useful predictive models, as well as more detailed heat maps, that empower clinicians and executive decision makers to proactively identify and assist those who are at greatest risk.

5. Conclusions

There has been a statistically significant increase in the incidence of heat related diagnoses at VA over the 18-year assessment period. During this timeframe, there has also been an increase in the association between HRI's and poor health status, as well as specific demographics. In addition, the increase in HRI over time does not strictly follow the expected geographic North-South climate trends, and no US state has been immune from HRIs.

Author agreement

All authors certify that they have seen and approved the final version of the manuscript being submitted. All authors warrant that the article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere

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Declaration of Competing Interest

Authors declare that there is no financial interest, personal interest, competing interests, or belief that could affect objectivity.

Supplementary materials

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