Geographic and demographic variation in worry about extreme

heat and COVID-19 risk in summer 2020

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ETHICAL STATEMENT

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ABSTRACT

Extreme heat is a major health hazard that is exacerbated by ongoing human-caused climate change. However, how populations perceive the risks of heat in the context of other hazards like COVID-19, and how perceptions vary geographically, are not well understood. Here we present spatially explicit estimates of worry among the U.S. public about the risks of heat and COVID-19 during the summer of 2020, using nationally representative survey data and a multilevel regression and poststratification (MRP) model. Worry about extreme heat and COVID-19 varies both across states and across demographic groups, in ways that reflect disparities in the impact of each risk. Black or African American and Hispanic or Latino populations, who face greater health impacts from both COVID-19 and extreme heat due to institutional and societal inequalities, also tend to be much more worried about both risks than white, non-Hispanic populations. Worry about heat and COVID-19 were correlated at the individual and population level, and patterns tended to be related to underlying external factors associated with the risk environment. In the face of a changing climate there is an urgent need to address disparities in heat risk and develop responses that ensure the most at-risk populations are protected.

Keywords: extreme heat, COVID-19, risk perception, survey research, MRP, health disparities

1 Introduction

Extreme heat is the leading cause of weather-related mortality in the U.S., and increases in both magnitude and duration of extreme heat events in the near future will continue to impact human health (Ebi et al. 2021). The hazard of extreme heat also intersects with, and is compounded by, other environmental and public health hazards (Wilhelmi and Hayden 2010). The COVID-19 pandemic has caused severe impacts and strained public health infrastructure, while also exacerbating risks from heat through multiple mechanisms including reduced access to cooling shelters or cool public spaces and direct health and economic burdens on more vulnerable populations (Martinez et al. 2020; Thomas et al. 2020; Wilhelmi et al. 2021).

Risk perceptions, which can include cognitive judgements about risks as well as affect, or emotional responses, are important drivers of health protective behaviors. Risk perception can play an important role in reducing negative heat health effects through making appropriate adaptive or behavioral changes (Hass et al. 2021). Similarly, risk perception of COVID-19 has been shown to be positively correlated with protective health behaviors in a large cross-national survey (Dryhurst et al. 2020) and in other U.S. surveys early in the pandemic (Bruine de Bruin and Bennett 2020; Garfin et al. 2021). A recent review of heat risk perception research in the past decade (2010-2020) highlighted the need for studies with larger geographic areas and representative population samples for various sub-populations in urban and rural locations (Hass et al. 2021).

In response to these research needs and the ongoing impacts from extreme heat and its interactions with COVID-19, we describe here a spatially explicit descriptive analysis of worry among the U.S. public about the risks of both extreme heat and COVID-19 during the first

summer of the pandemic in July–Sept 2020. We use a dataset comprising three waves of U.S. nationally representative survey data on extreme heat and COVID-19 with questions about worry and experiences, direct and indirect impacts, protective behaviors, household coping capacity, and self-efficacy. Here we focus on worry about extreme heat and COVID-19, using two parallel sets of survey questions about each hazard. Using this dataset, we develop a small-area estimation model to map worry about heat and COVID-19 at the state level across the U.S. Building on prior small-area estimation models, we generate state-level estimates of worry about each risk for the total adult population and census demographic subgroups by both gender and race/ethnicity, demographic factors that have been shown to be associated with environmental hazard and public health disparities and differences in risk perceptions. Our analyses are primarily descriptive and exploratory, with the goal of characterizing geographic patterns in worry about each risk among the general U.S. population and key demographic subgroups.

1.1 Heat health risks & intersecting vulnerabilities with COVID-19

To date, extensive research has established temperature-mortality relationships (Anderson et al. 2013; Gasparrini et al. 2015; O'Lenick et al. 2020), explored the interactions among heat hazard, urban populations, and the built environment with a focus on vulnerable groups, urban heat island effect, and heat health risks (Harlan et al. 2013; Heaton et al. 2014; Gronlund et al. 2018; O'Lenick et al. 2019). Previous studies proposed methods for mapping extreme heat vulnerability (Reid et al. 2009; Uejio et al. 2011; Heaton et al. 2014; Conlon et al. 2020) and provided key insights into the processes that drive social vulnerability to extreme heat, including individual decision-making and broader societal factors (Wilhelmi and Hayden 2010;

Hayden et al. 2011, 2017; Harlan et al. 2013; Heaton et al. 2014; Esplin et al. 2019; Howe et al. 2019).

While not unique to heat hazard, factors such as economic and housing security, access to healthcare, education, and safe environments play important roles in reducing heat health risks (Thomas et al. 2020). These factors vary geographically, among populations, and are subject to macro-scale environmental and socio-economic stressors. Economic downturns can amplify heat risks by affecting stable housing and employment, which in turn could lead to reduced household resources for cooling and limited access to healthcare (Wilhelmi and Hayden 2010).

The COVID-19 pandemic was the most recent example of these macro-scale impacts on extreme heat risks as well as the intersectionality in social vulnerability. Many sub-populations vulnerable to heat were also those most affected by the COVID-19 pandemic (Karaye and Horney 2020; Thomas et al. 2020; Mackey et al. 2021; Wilhelmi et al. 2021). Wilhelmi et al. (2021) provided empirical evidence that the intersection of the COVID-19 pandemic and hot weather exacerbated systemic vulnerabilities as well as health and energy inequities and reduced the capacity of millions of people in the U.S. to cope with heat. With over a quarter of the U.S. population experiencing heat-related symptoms during the summer of 2020, Wilhelmi et al. (2021) demonstrate that those who were most vulnerable were women, those in low-income households, and minoritized racial and ethnic populations. Limited access to cooling as well as COVID-19 related social isolation played a major role in adverse heat health effects (Wilhelmi et al. 2021).

Access to air-conditioning can reduce heat-related morbidity and mortality; the use of a cooling center or an air-conditioned space such as a library, mall, or community center can reduce negative health impacts in those who are vulnerable to extreme heat (Widerynski et.al., 2017). Cooling centers can provide those with limited access to air-conditioning, or those without the resources to operate air-conditioning, a means to reduce risks associated with exposure to extreme heat (Semenza et al., 1996; Abbinett et al., 2020). However, the COVID-19 pandemic hindered government efforts to prevent negative impacts from exposure to extreme heat through restricted access to cooling centers and reduced hours for alternative means of cooling such as pools and beaches. During the summer of 2020, in response to COVID-19, the U.S. experienced an unprecedented economic downturn, not seen since the Great Depression CRS 2021). This downturn in the economy was closely related to newly enacted public health policies, including lockdowns and travel restrictions. As a result of these policies, cooling shelters across the U.S. closed or provided reduced hours of access, and other designated shelters such as libraries and malls restricted their hours and occupancy in response to reduced staffing and COVID transmission risk. In addition to traditional barriers to the use of cooling centers such as lack of walkability and poor transportation options to a designated center, one study noted that some type of social distancing or mask mandate was required to enter all centers in their study (Jin and Sanders 2022), policies that were enacted to reduce the spread of COVID-19, but which may have reduced access. Pandemic related budget cuts also resulted in reduction in staff and operating hours for pools and beaches in addition to cooling shelters (Jin and Sanders, 2022). These mandated closures and reductions in services of publicly accessible cooling spaces

place those who are more vulnerable at higher risk during extreme heat (Martinez et al. 2020; Salas et al. 2020; Shumake-Guillemot et al. 2020).

1.2 Risk perceptions and worry as a key factor in hazard/health vulnerability

Many studies of natural hazard preparedness and health behavior (Brewer et al. 2007; Wachinger et al. 2013; Shreve et al. 2016) highlight that risk perception and worry can have an important—yet context dependent—role in reducing impacts from hazards. People's risk perceptions and their responses to risk information are influenced by a complex mix of cognitive processes, affect and emotion, perceived and actual exposure to hazards, past hazard experience, trust, worldviews, and other factors (Weinstein 1989; Slovic et al. 2004; Peacock et al. 2005; McComas 2006; Lazo et al. 2015; Demuth et al. 2016; Rickard et al. 2017). Risk perception is multifaceted, with both cognitive and affective or emotional dimensions. Worry about a risk can be considered an affective or emotional dimension of risk perception, or a closely aligned construct. Although worry does not always strongly correlate with cognitive measures of risk perception across all types of hazards (Sjöberg 1998), worry about a risk has been shown to be a better predictor of behavioral responses than cognitive risk perceptions in some circumstances (Peters et al. 2006), and is strongly associated with cognitive measures of perceived risk (perceived likelihood and severity) in the context of both extreme heat and COVID-19 (Howe et al. 2019; Sobkow et al. 2020). Worry about the risk has also been found to be directly associated with protective behaviors for COVID-19 (Prete et al. 2020; Coifman et al. 2021; Thompson et al. 2022).

Prior research on extreme heat risks highlighted risk perception as a key factor in adaptive and coping capacity (Hayden et al. 2011, 2017; Lane et al. 2014; Madrigano et al. 2018) and demonstrated its role in mitigating negative health effects by promoting behavior change (Akompab et al. 2013; Esplin et al. 2019; Hass et al. 2021). Similar to other natural hazards, people's risk perception of extreme heat and ability to take protective actions may be influenced by sociodemographic characteristics, experience, geographic location, or features of the natural and built environment. These factors can result in geographic variability and sociodemographic differences, with higher risk perception among more vulnerable populations, including racial and ethnic minorities, low income populations, and those who are in poor health (Hass et al. 2020).

At the onset of the global COVID-19 pandemic, scholars began to investigate populations' risk perception and worry about COVID-19, its role in motivating protective health behaviors, and factors influencing perceptions of this new and rapidly evolving global hazard (Barattucci et al. 2020; Prete et al. 2020; Wise et al. 2020; Ye and Lyu 2020; Attema et al. 2021). During the first year of the pandemic, Dryhurst et al. (2020) conducted a multi-national study in ten countries across Europe, America, and Asia using national survey samples. People's risk perception of COVID-19 was higher in those with direct personal experience with the virus, and in those who hold more prosocial worldviews. As with other hazards, elevated risk perception of COVID-19 was significantly correlated with adoption of protective health behaviors (Dryhurst et al. 2020). Studies of the U.S. population during the first year of the pandemic show a similar pattern of association between risk perception and protective behaviors (Bruine de Bruin and

Bennett 2020; Garfin et al. 2021), or worry and protective behaviors (Coifman et al. 2021; Thompson et al. 2022).

1.3 Geographic variation in risk perception and association between risk perception and underlying risk

While researchers have made progress in understanding individual predictors of risk perceptions and associations between risk perception and behavior, there remain gaps in our understanding of how risk perceptions vary across geographies and scales; how spatial patterns vary across demographic subpopulations; and how spatial patterns are associated with geographic factors such as hazard exposure and governance. Recent studies have begun to address these gaps (Howe et al. 2019; Allan et al. 2020; Ripberger et al. 2020). For instance, Allan et al. (2020) map risk perceptions of eight extreme weather hazards across the U.S. in relation to exposure to each hazard. Howe et al. (2019) similarly use a small-area estimation model to map risk perceptions of heat waves at the state, county, and census tract scale in the U.S., finding patterns in risk perceptions associated with patterns of exposure due to urban heat island effects. However, despite a growing recognition of heat health threats, only a few studies have examined heat risk perception at the national scale (e.g., Howe et al. 2019; Esplin et al. 2019). Despite the fact that a majority of the U.S. population experience hot weather in their everyday lives and during increasingly frequent heat waves, a recent study showed that 42 percent of Americans were not worried about heat risks to their health in 2020 (Wilhelmi et al. 2020). Research on geographic differences in heat risk perception in the US— across the urbanrural continuum, among sociodemographic subpopulations, and in a multi-hazard context —is needed to understand public experiences and responses to this growing climatic hazard.

2 METHODS

2.1 Survey data collection

We collected three waves of U.S. nationally representative survey data (total n=3036 completed responses) through a probability-based sample via an online panel in July, August, and September 2020 via the Ipsos Knowledgepanel Omnibus. Panel members were recruited using address-based probability sampling methods, and those who do not have internet access were provided access by Ipsos. Alongside our survey questions, we also collected demographic information provided by panel members and high-resolution geographic data indicating each respondent's household location, within a radius of 100m. Our sample contained responses from all 50 states and the District of Columbia, and the proportion of responses from each state was not significantly different from their proportion of the national population (paired test: t(50)=0.00, p=1).

The survey included 18 questions about COVID-19 and extreme heat worry, experiences of each hazard, symptoms of heat stress and COVID-19, household coping capacity, self-efficacy, and protective behaviors, and reported challenges to engaging in heat-protective behavior during the pandemic. We provide an individual-level analysis of personal experiences and protective behaviors in Wilhelmi et al. (2021), and full survey questions and descriptive results are available in Wilhelmi et al. (2020). Here we report on two parallel indices based on sets of questions focused on worry about extreme heat and COVID-19, an affective component

of risk perception. This item was based on one from a previous survey of U.S. residents' heat risk perceptions (Howe et al. 2019), and has five response options (from "not worried at all" to "extremely worried"). Next, respondents answered a multi-part question about how worried they were about the risk of heat or COVID-19 to their health in specific places: at home, at work, outdoors, on public transportation, and in indoor public places, on a matching five-point scale. Our worry indices are the sum of responses to the first question about worry about general personal health to either heat or COVID-19, and worry about each risk at home and outdoors. Each index is set on a 0 ("not worried at all" on all 3 items) to 100 ("extremely worried" on all 3 items) scale. Each index had acceptable internal consistency (heat, Cronbach's alpha = 0.82; COVID-19, Cronbach's alpha = 0.75).

Table 1: Unweighted response counts and question wordings for each item comprising the heat worry scale and COVID-19 worry scale. Weighted percentages in parentheses.

Category	Item	Not worried at all	A little worried	Moderatel y worried	Very worried	Extremely Worried	Missing / no response
Heat	Health worry - general ¹	1344 (42%)	704 (23%)	631 (22%)	208 (7%)	137 (5%)	12 (0%)
	Worry at home ²	1945 (62%)	584 (19%)	278 (10%)	104 (4%)	59 (2%)	66 (2%)
	Worry outdoors ³	842 (26%)	865 (27%)	669 (22%)	350 (13%)	255 (9%)	55 (2%)
COVID-19	Health worry - general ⁴	471 (15%)	684 (22%)	817 (26%)	577 (20%)	476 (17%)	11 (0%)
	Worry at home ⁵	1988 (64%)	667 (22%)	227 (8%)	53 (2%)	51 (2%)	50 (2%)

Worry outdoors ⁶	1180 (36%)	987 (32%)	520 (18%)	172 (7%)	143 (6%)	34 (1%)
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¹ "A heat wave is a period of unusually and uncomfortably hot weather. How worried, if at all, are you about the effects of heat waves on your health?"

2.2 Additional comparison data

For additional exploratory analysis and to contextualize our results, we also use secondary data indicators related to COVID-19 in summer 2020 and climate and weather data for the same period. SARS-CoV-2 case, mortality/morbidity, transmission, and risk data were acquired from COVID Act Now via API (COVID Act Now 2021). COVID-19 time-series data were acquired from March 2020 through September 2021 at daily temporal and state spatial scales for all U.S. states and two U.S. territories. Relevant COVID-19 data were aggregated for each state for the 30 days before, and inclusive of, the days when Ipsos surveys were administered. Days averaged for wave 1 of survey data collection included June 21, 2020 to July 20th, 2020. Days averaged for wave 2 of survey data collection included July 18, 2020 to August 16th, 2020. Days averaged for wave 3 of survey data collection included August 18, 2020 to September 16th, 2020.

We acquired climate and weather data for each month of survey data collection for comparison purposes from the NOAA National Centers for Environmental Information (NCEI 2022). We collected county-level mean, minimum, and maximum monthly temperature anomalies (July, August, September) for 2020 (and associated long-term normals for 1991-

² "During periods of extreme heat or very hot weather, how worried are you about the risk of heat to your health in the following places?" [At home]

³ "During periods of extreme heat or very hot weather, how worried are you about the risk of heat to your health in the following places?" [Outdoors]

⁴ "Considering both your risk of contracting it and the seriousness of the illness, how worried are you about the effects of the coronavirus (COVID-19) on your health?"

⁵ "Currently, now worried are you about the risk of the coronavirus (COVID-19) to your health in the following places?" [At home]

⁶ "Currently, how worried are you about the risk of the coronavirus (COVID-19) to your health in the following places?" [Outdoors]

2020). We then used 2019 county populations to calculate state-level population-weighted means for each variable.

2.3 Modeling geographic patterns in worry about each risk with multilevel regression and poststratification

We used multilevel regression and poststratification (MRP) to estimate state-level worry indices from our survey data, which represent a mean value for the adult population of each state. MRP uses individual-level data from surveys alongside Census data or other data on population characteristics to model and estimate responses within subpopulation groups, typically geographic units like U.S. states or counties based on national-level surveys (Park et al. 2004; Lax and Phillips 2009; Howe et al. 2015; Mildenberger et al. 2016; Howe 2018; Caughey and Warshaw 2019; Allan et al. 2020). MRP has also been used to estimate geographic patterns in public health indicators from national datasets (Zhang et al. 2014, 2015; Downes et al. 2018; Howe et al. 2019). We developed parallel MRP models predicting our indices of worry about heat and COVID-19, using the same set of predictor variables for each outcome variable.

Studies applying small-area estimation to public beliefs, attitudes, and behaviors related to environmental hazards and climate change have focused on the total adult population of geographic subunits such as states, counties, and census tracts (Howe et al. 2015, 2019; Mildenberger et al. 2016; Howe 2018). However, small-area estimates using techniques like MRP need not be limited to the general population, and can similarly be produced for demographic subgroups (Mildenberger et al. 2017). Here we detail a novel extension of previous MRP efforts by presenting state-level estimates for both 1) the total adult population, and 2) the adult population of subgroups defined by race/ethnicity and gender Census categories.

As the first step in our MRP, we fit a set of multilevel linear regression models with unstructured priors to the individual-level survey data for each outcome variable (worry indices for heat and COVID-19). The model includes random effects for individual demographic variables (gender, age, race/ethnicity, and gender by age by race/ethnicity). We use these individual predictor variables because they have tended to be predictive of health disparities, hazard vulnerabilities, and differences in risk perception driven by social, economic, and institutional inequities in prior research (Cutter and Finch 2008; Wilhelmi and Hayden 2010; Howe et al. 2019; Karaye and Horney 2020; Mackey et al. 2021). Individual-level predictors in MRP models are limited to those available in the primary survey data and for which joint population distributions are available at the population level, typically from census or similar sources. In our case, we use a combination of individual-level predictors (gender by age by race/ethnicity) from the 2019 5-year American Community Survey (ACS). We also include geographic random effects for the state, census region, and census division. One set of models averages over the three waves of data collection, while a second set includes random effects for the survey month (and associated time-geography interactions), to allow for estimation of changes in worry over the course of summer 2020. Finally, we include a set of state-level fixed effects also from the 2019 5-year ACS, based on fixed effects adopted in Howe et al. (2019): the percent of adult residents with a bachelor's degree or higher, the percent of the population whose income was below poverty level, and the percent of the population 65 years and over with a disability. Models were fit in R using the lme4 package's LMER function, using the model

specification outlined below (Bates et al. 2014). Replication code and data are available to accompany publication of this article (Howe 2022).

For each respondent i our model estimates their value on the corresponding worry index, represented by $y_{[i]}$. The model for each dependent variable is specified as:

$$y_{i} \sim N(\beta_{0} + \alpha_{gender[i]} + \alpha_{age[i]} + \alpha_{race.eth[i]} + \alpha_{gender:age:race.eth[i]} + \alpha_{state[i]} + \alpha_{time[i]}$$

$$+ \alpha_{state:time[i]}, \sigma^{2})$$

$$\alpha_{gender} \sim N(0, \sigma^{2}), \text{ for } gender = 1,...,2$$

$$\alpha_{age} \sim N(0, \sigma^{2}), \text{ for } age = 1,...,7$$

$$\alpha_{race.eth} \sim N(0, \sigma^{2}), \text{ for } race.eth = 1,...,5$$

$$\alpha_{gender:age:race.eth} \sim N(0, \sigma^{2}), \text{ for } gender:age:race.eth = 1,...,70$$

$$\alpha_{state} \sim N(0, \sigma^{2}), \text{ for } state = 1,...,51$$

$$\alpha_{time} \sim N(0, \sigma^{2}), \text{ for } time = 1,...,51$$

Each variable is indexed over individual *i* and over response categories for gender (census categories: male, female), age group (18-24; 25-34; 35-44; 45-54; 55-64; 65-74; 75 years and over), race/ethnicity (census categories: Black, non-Hispanic; Hispanic or Latino; White, non-Hispanic; Asian, Native Hawaiian and Pacific Islander, American Indian and Alaska Native, or some other race non-Hispanic; two or more races, non-Hispanic), the interaction of gender by age by race/ethnicity, geography (state, census division, and census region), time (month of survey, in the second set of models), and the interaction of time and geography respectively.

Each variable is modeled as drawn from a normal distribution with mean zero and estimated variance σ^2 . The geography variable, *state*, is modeled as follows:

$$\alpha_{state[s]} \sim N(\alpha_{division[s]} + \alpha_{region[s]} + \beta_1 \cdot edu_s + \beta_2 \cdot pov_s + \beta_3 \cdot dis_s, \sigma^2)$$
, for $s = 1,...,51$

Where *edu*, *pov*, and *dis* represent the state-level fixed effects discussed above for education, poverty, and disability status.

We next poststratify our fitted regression model to the joint population distribution for each state, resulting in a predicted index value for each gender by age by race/ethnicity by state population cell. Predicted values are then weighted by the cell's population within each state to produce an estimated value for the combined adult population of that state. We further estimate 95 percent confidence intervals for each state-level estimate using 999 bootstrap resamples of our primary survey data and refitting our MRP model to each resampled dataset. In the following analyses we also produce state-level estimates for subsets of the population within each state for which their individual-level predictors exhibit positive variance: for men and women respondents separately, and for four census race/ethnicity categories: the white, non-Hispanic population, the Black, non-Hispanic population, the Hispanic or Latino (Latinx) population, and the Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander, or other non-Hispanic population (this category is an aggregate of four census categories to match the corresponding race/ethnicity question associated with our primary survey data). We acknowledge that there is diversity within these Census gender and race/ethnicity categories and that category labels may not be inclusive of the whole population. We do not produce estimates

for subsets of the population by age group, because the variance of the age group predictor was near zero in each model.

3 RESULTS

3.1 Mapping worry about heat risk

For the July-September 2020 survey period, we estimate that the mean on the heat worry scale for the U.S. adult population was 26.4±1.0 (on a 0-100 scale), which is between the "a little worried" and "moderately worried" responses on the five point scale from "not worried at all" to "extremely worried" used in our survey questions. Race/ethnicity and gender were the strongest individual-level predictors in the model (there were no significant differences across age groups). Across the four census race/ethnicity categories for which we have data by population, Hispanic or Latino respondents (mean 34.0±2.5), Black or African American, non-Hispanic respondents (mean 33.8±2.4), and Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander, or other non-Hispanic respondents (mean 32.8±3.5) each averaged higher worry about extreme heat than white, non-Hispanic respondents (mean 25.4±1.6). On average across the July-September 2020 season, women had an estimated worry index of 27.8±1.2 compared to 24.9±1.1 for men.

Heat worry also varied across populations at the state level (Figure 1), with a mean of 25.2 (SD = 3.1). The heat worry scale was generally lowest among residents in Midwestern states, including Wisconsin (19.0 ± 3.2), Iowa (20.2 ± 4.2), and South Dakota (20.8 ± 5.0). The heat worry scale was highest in certain Western and Southern states, including California (31.5 ± 2.6), the District of Columbia (31.5 ± 7.1), and Alabama (31.2 ± 6.5).

We further map differences in heat worry between census race/ethnicity categories (Figure 2), which reveals a second-order pattern of disparities in worry about heat between white, non-Hispanic residents and other census race/ethnicity categories. Differences in the heat worry scale between Black or African American non-Hispanic residents and white, non-Hispanic residents were greatest in the Midwest (with the greatest disparities in Missouri, Iowa, and Minnesota [13 points]) and smallest in Hawaii (1 point), and California (2 points). Differences in the heat worry scale between Hispanic or Latino residents and white, non-Hispanic residents were greatest in Ohio, Michigan, and Wisconsin (13 points), and smallest in California and Hawaii (4 points), and New Mexico (5 points). For the combined categories of Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander, or other non-Hispanic residents, differences between white, non-Hispanic residents were greatest in Missouri, Iowa, and North Dakota (11 points), and smallest in California, Hawaii, and New Mexico (4 points).

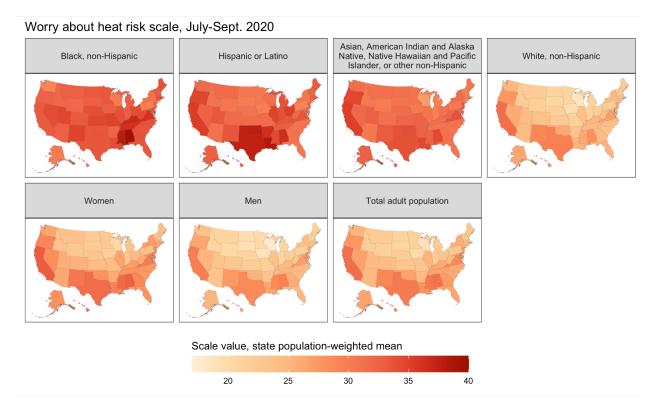


Figure 1: State-level estimates of heat worry scale for the July-September 2020 period in selected demographic groups.

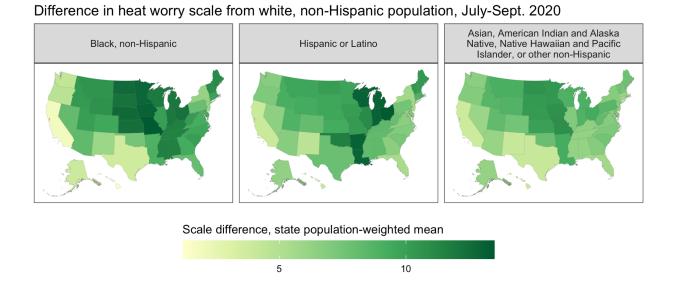


Figure 2: State-level map of differences in estimated heat worry scale from the white, non-Hispanic population for selected race/ethnicity categories.

3.2 Mapping worry about COVID-19 risk

For the July-September 2020 survey period, we estimate that the mean COVID-19 worry index for the U.S. adult population was 30.4±1.0 (on a 0-100 scale), which is between the "a little worried" and "moderately worried" responses on the five-point scale used in our question items. As with worry about heat, race/ethnicity and gender were the strongest individual-level predictors in the model, with no significant differences among age groups. Across the four race/ethnicity categories for which we have data by population, Hispanic or Latino respondents (mean 39.0±2.5), Black or African American, non-Hispanic respondents (mean 40.5±3.2), and Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander, or other non-Hispanic respondents (mean 37.1±2.6) each averaged higher worry about COVID-19 than white,

non-Hispanic respondents (mean 28.9±1.6). On average across the July-September 2020 season, women had an estimated worry index of 32.4±1.2 compared to 28.2±1.1 for men.

Worry about COVID-19 varied across populations at the state level (Figure 3), with a mean of 29.0 (SD = 2.8). The COVID-19 worry scale was lowest in Iowa (24.5 \pm 3.1), West Virginia (24.9 \pm 3.0), and Wyoming (25.2 \pm 3.4), and highest in the District of Columbia (37.5 \pm 4.7), California (36.1 \pm 2.2), and Hawaii (33.8 \pm 4.0).

As above, we also examine differences in worry about COVID-19 between census race/ethnicity categories (Figure 4), which again shows a second-order pattern of disparities by race/ethnicity. Similarly to worry about heat, differences in the COVID-19 worry scale between Black or African American non-Hispanic residents and white, non-Hispanic residents were greatest in the upper Midwest, including Missouri (15 points), Iowa (14 points), and Minnesota (13 points), and smallest—although still substantial—in Hawaii (7 points), New Mexico (8 points), and California (8 points). Differences in the COVID-19 worry scale between Hispanic or Latino residents and white, non-Hispanic residents were greatest in Ohio, North Dakota, and Missouri (12 points), and smallest in New Mexico, California, and Hawaii (6 points). For the combined categories of Asian, American Indian and Alaska Native, Native Hawaiian and Pacific Islander, or other non-Hispanic residents, differences between white, non-Hispanic residents were greatest in Missouri, North Dakota, and West Virginia (10 points), and smallest in New Mexico (3 points), California (4 points), and Hawaii (4 points).

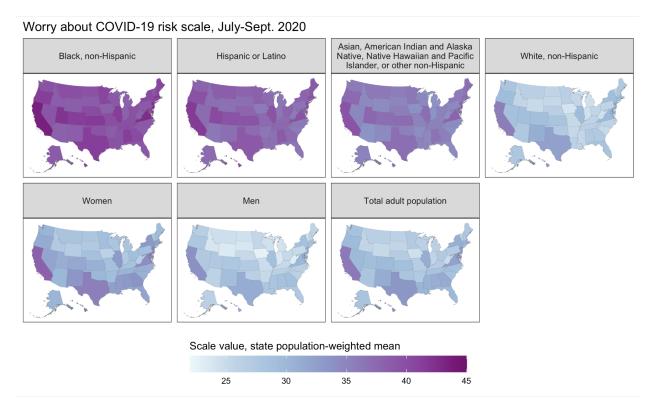


Figure 3: State-level estimates of COVID-19 worry scale for the July-September 2020 period in selected demographic groups.

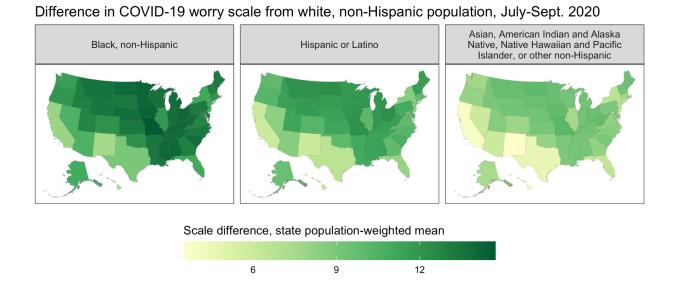


Figure 4: State-level map of differences in estimated COVID-19 worry scale from the white, non-Hispanic population for selected race/ethnicity categories.

3.3 Comparing worry about heat and COVID-19 over time

Using our second set of models that incorporate monthly random effects (with geographic interactions) for each of the three survey waves, we estimate national- and state-level worry about extreme heat and COVID-19 for July, August, and September 2020 (Figure 5). Across the national population, the heat worry index in July averaged 24.8±1.5, 26.9±1.4 in August, and 27.3±1.2 in September. The COVID-19 worry index in July averaged 30.3±1.1, 31.1±1.5 in August, and 29.7±1.2 in September.

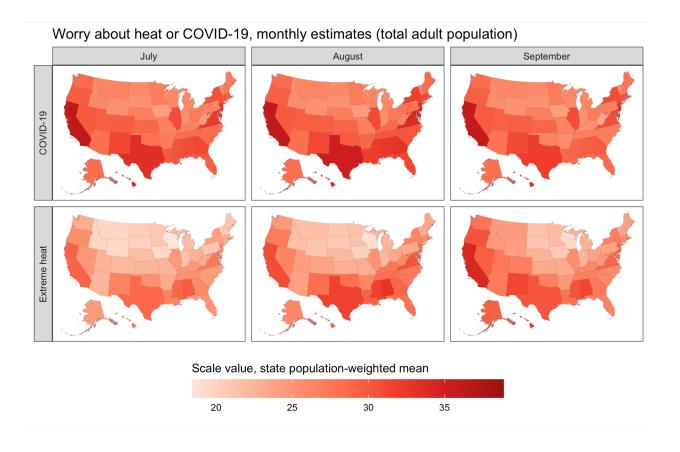


Figure 5: Monthly state-level estimates of COVID-19 (top) and heat (bottom) worry scales, for the total adult population of each state.

Worry about extreme heat and COVID-19 were also strongly correlated with each other at the state level (r=0.78, p<0.000). Figure 6 illustrates the relationship between each state-by-month estimate. This pattern reflects the similar strong correlation at the individual level between each index (r=0.64, p<0.000), and a similar pattern of estimates across race/ethnicity and gender categories from the MRP model, as described above.

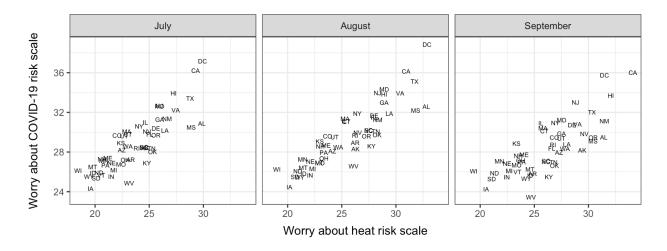


Figure 6: Scatter plots of estimated monthly state-level heat worry scale (x-axis) and COVID-19 worry scale (y-axis) for July, August, and September 2020.

3.4 Risk metrics and worry about COVID-19 and extreme heat

We further analyze our state-month estimates of worry about extreme heat and COVID-19 by comparing contextual indicators of risk for each period. Figure 7 illustrates a month-by-month comparison of estimated state-level worry about extreme heat and the climatological monthly mean temperature (top) or the monthly mean temperature anomaly for 2020 (bottom), weighted to the population distribution within each state (NCEI 2022). There was a moderate correlation between state-level monthly heat worry and the climatological mean temperature (r=0.25, p=0.001), but no correlation between heat worry and the monthly mean temperature anomaly during 2020 (r=.01, p=.901).

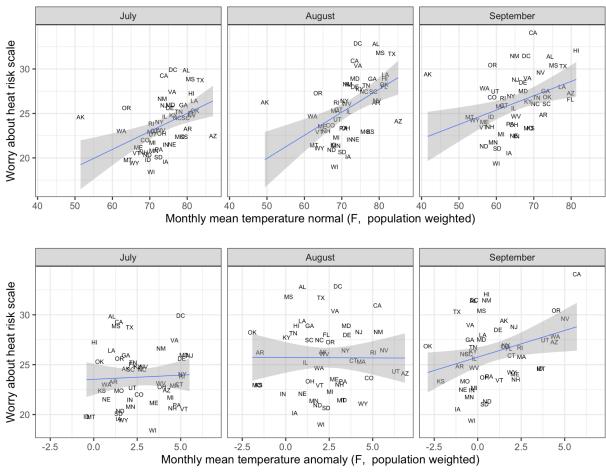


Figure 7: Scatter plots of estimated July, August, and September 2020 monthly state-level heat worry scale (y-axis) as compared to the corresponding long-term monthly mean temperature climatology (top) and monthly mean temperature in 2020 (bottom).

Figure 8 illustrates a monthly comparison of state-level COVID-19 worry to the state-level cumulative COVID-19-associated death rate (top) and average state-level test positivity ratio (bottom) for each month (COVID Act Now 2021). There was a moderate positive correlation between the COVID-19 worry index and the cumulative death rate (r=0.37, p<0.000), but no consistent relationship between the worry index and the SARS-CoV-2 test positivity ratio (r=.02, p=.786), a measure of the current COVID-19 risk environment. There was a similar lack

of association between state-level worry and other indicators of the COVID-19 current risk environment, including case density and infection rate.

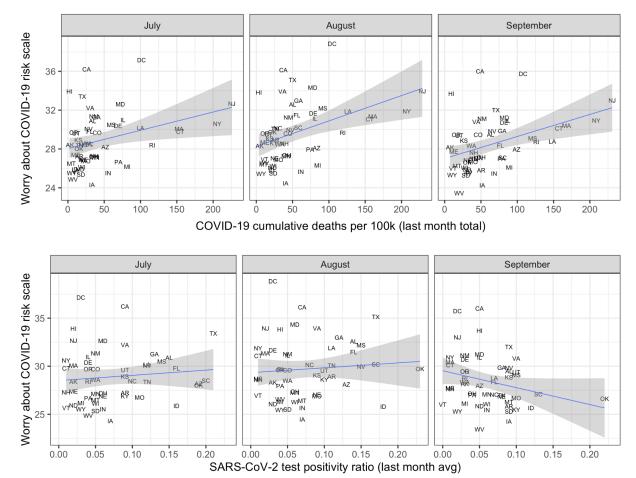


Figure 8: Scatter plots of estimated July, August, and September 2020 monthly state-level COVID-19 worry scale (y-axis) as compared to the corresponding state-level cumulative COVID-19 death rate per 100,000 people (top) and monthly average SARS-CoV-2 test positivity ratio (bottom).

4 DISCUSSION

Our results provide both a national-level, state-level, and demographic perspective on how the U.S. population perceived the dual risks of extreme heat during summer 2020. Using a matched set of items in a nationally representative survey, we found that Americans were somewhat more worried about COVID-19 as a risk to their health than extreme heat. Further, at the individual and population level perceptions of each risk appear to be strongly correlated with each other: individuals and populations who have elevated perceptions of one risk also tended to have elevated perceptions of the other risk. This is in contrast to a pattern expected under a "finite pool of worry" effect, where worry about the novel risk of COVID-19 might displace worry about the long-term environmental risk of extreme heat (Weber 2006), and is consistent with other research showing that concern about climate change was not displaced by concern about COVID-19 in a U.K. sample (Evensen et al. 2021).

Our results also illustrate geographic variation across populations at the state level for both worry about extreme heat and COVID-19. Variation in worry about each risk tended to be associated with certain external objective factors associated with the risk environment for both extreme heat and COVID-19, but not others. For example, as reflected in previous studies of heat risk perceptions (Howe et al. 2019), populations in warmer climates—on average—tended to be more worried about the risk of extreme heat than those in cooler climates. However, geographic patterns in heat worry were not associated with short-term differences in temperature: people in states that were warmer than normal over the month prior to each survey did not tend to be more worried than those in states that were cooler than normal. Similarly, the state-level pattern of COVID-19 risk shows associations with a long-term risk indicator—the cumulative death rate—

but not the short-term indicator of test positivity. While these exploratory tests of association are not conclusive, they suggest that perception of both risks may be associated with some metrics of the risk environment, but tends to be most associated with longer-term or lagging environmental risk indicators, rather than short-term indicators. This pattern illustrates potential challenges for risk communication and behavior change in the context of fast-developing hazards, like COVID-19 or heat waves in areas not accustomed to them, if concern about the hazard is not quickly responsive to changes in the underlying risk.

Most studies applying small-area estimation to survey data produce estimates for the total adult population of each geographic subunit (Howe et al. 2015, 2019; Mildenberger et al. 2016; Howe 2018). Building on these efforts, we leveraged the modeling capability of MRP and underlying data to map both state-level estimates for the total adult population and estimates for the population of demographic subgroups in Census race/ethnicity and gender categories. By doing so, we illustrate not only cross-state geographic variation in worry about each risk across the total population, but also geographic variation within demographic subgroups and, in some cases, the strong variation between demographic subgroups. Our results show large differences in worry about both extreme heat and COVID-19 across Census race/ethnicity categories that match or exceed variation across states among the overall population: even in states where worry among Black or African American and Hispanic or Latino residents was low relative to the same subpopulation in other states it was still higher than worry among white, non-Hispanic residents in nearly every other state. For example, we estimated that the average Black or African American resident of Indiana (the state where COVID-19 worry was lowest among Black or African Americans) was more worried about COVID-19 than the average white, non-Hispanic

resident of California (the state where worry was highest among white, non-Hispanics). Similarly, we estimate that the average Hispanic or Latino resident of Pennsylvania (the state where heat worry was lowest among Hispanics or Latinos) was more worried about heat than the average white, non-Hispanic resident of every state except Texas and California. Furthemore, we illustrated that disparities in worry among race and ethnicity categories were not uniform across the country, but instead vary geographically themselves. Overall, this pattern of large differences in worry about heat and COVID-19 risks by race and ethnicity tends to correspond with disparities by race and ethnicity in the impact of each hazard. Black or African American and Hispanic or Latino populations have experienced disproportionately higher rates of infection, hospitalization, and mortality from COVID-19, compared with non-Hispanic white populations (Mackey et al. 2021). Similarly, the health effects of extreme heat exhibit disparities by race and ethnicity (Gronlund 2014), along with racial and ethnic disparities in heat exposure in the U.S. (Benz and Burney 2021). Strategies to mitigate heat-related illness, such as cooling centers, may not be readily available because of pandemic related closures or may not be perceived as safe by the public because of risk of COVID transmission. Furthermore, a study in Alabama in the summer of 2020 indicated that Black or African American participants reported a lack of trust in government related to recent police brutality and the safety of accessing public cooling spaces, placing those who may be more vulnerable at risk of negative effects from extreme heat exposure (Wang et al. 2021).

Compared to differences across gender and race/ethnicity categories, differences in worry about heat and COVID-19 by age group were nonexistent in our models. This pattern is similar to prior findings showing little evidence of variation in risk perceptions of heat by age at the

individual level, or between places with different age compositions, despite age being an underlying factor in heat health risk (Esplin et al. 2019; Howe et al. 2019). Younger people were somewhat more likely to experience health symptoms from extreme heat during summer 2020, but age was not a significant predictor of other negative effects from heat during the early stages of the COVID-19 pandemic (Wilhelmi et al. 2021). The lack of a significant association between age and worry about COVID-19 is consistent with cross-national and U.S. survey results from early in the pandemic (Dryhurst et al. 2020), but other U.S. survey results have shown a positive association between age and perceived risk of dying or severe consequences of COVID-19, and a negative association between age and perceived risk of getting COVID-19 (Bruine de Bruin 2021; Garfin et al. 2021). These mixed results for age and perceptions of specific COVID-19 risks potentially explain the lack of an association between age and our less-specific general measure of worry about the health effects of COVID-19 in this study.

This study has several limitations. First, our nationally representative sample size limits our ability to understand worry among smaller sub-groups of vulnerable populations than the large race/ethnicity, gender, and age categories we use here. Since we use a representative sample, low-population states are less represented in our data set and therefore tend to exhibit larger confidence intervals in our model estimates. To reduce this source of error, future research should supplement national probability-based sample data with targeted oversamples in regions with low populations or areas of focus with particularly at-risk populations. A second limitation is that our survey dataset combined the U.S. Census race categories of Asian American, American Indian/Alaska Native and Native Hawaiian/Other Pacific Islander races into one category, which prevents detailed understanding of the diversity of responses within these

populations. In addition, this U.S.-based study included residents of the 50 states and the District of Columbia but did not include residents of U.S. territories, who have also been at risk of extreme heat and COVID-19. Further, we did not examine all possible sociodemographic predictors of worry about heat and COVID-19 since, for MRP modeling purposes we limited our individual-level predictors to demographic variables available as joint distributions in US Census data. However, the state and region-level variables in our model can account for possible unobserved predictors that vary geographically. For example, political affiliation is a strong predictor of risk perceptions of COVID-19 (Bruine de Bruin et al. 2020) and heat waves (Cutler et al. 2018), that also exhibits geographic variation and may be captured by the state-level random effects in our model. Lastly, this study is based on data collected at a particular point in time—July-September 2020—during the first year of the COVID-19 pandemic. Specific estimates, such as relative worry about COVID-19 between states, may not necessarily generalize to current or post-pandemic circumstances.

5 CONCLUSIONS

We present the first spatially explicit estimates of how the U.S. public perceived the dual risks of extreme heat and COVID-19 during the summer of 2020. Using nationally representative survey data and small-area estimation models, we showed that the extent to which populations worried about heat or COVID-19 is somewhat dependent on the state in which they live. Overall, however, we found that there are very different national landscapes of worry about each risk that reflect disparities in the impact of each risk by race/ethnicity. In particular, Black or African American and Hispanic or Latino populations, who have experienced greater health impacts

from both COVID-19 and extreme heat, also tended to be much more worried about both risks than were white, non-Hispanic populations. These differences in impacts, and associated risk perceptions, may be due to disparities in access to health care and greater exposure, among other institutional and societal inequalities (Benz and Burney 2021; Mackey et al. 2021).

Future research should apply a similar geographic lens to both risk perceptions and protective behaviors in the context of heat and other evolving hazards such as COVID-19. The methods we illustrate here to visualize geographic variation in worry about each risk across demographic subpopulations could be applied in the future to a wider range of hazards and can help communicators and policymakers understand disparities in perceptions and responses within their communities. In the face of a changing climate where more frequent, extended, and extensive temperature extremes are projected, there is an urgent need to address these disparities and develop locally designed and implemented heat action plans that ensure the most vulnerable are protected.

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SUPPLEMENTARY DATA

state est all.csv: this file contains state-level estimates of worry about heat risk (column

5) and worry about COVID-19 risk (column 8) for summer 2020, for the total adult population of

each state and the selected demographic subgroups described in this paper. Estimates are accompanied by the lower and upper bounds of their 95 percent confidence intervals, and sorted by state FIPS code.