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To cite this article: O V Wilhelmi *et al* 2021 *Environ. Res. Lett.* **16** 084060

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ENVIRONMENTAL RESEARCH
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OPEN ACCESS

RECEIVED
10 May 2021

REVISED
20 July 2021

ACCEPTED FOR PUBLICATION
23 July 2021

PUBLISHED
6 August 2021

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LETTER

Compounding hazards and intersecting vulnerabilities: experiences and responses to extreme heat during COVID-19

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Keywords: extreme heat, COVID-19, risk, vulnerability, survey, United States

Supplementary material for this article is available online

Abstract

Extreme heat is a major threat to human health worldwide. The COVID-19 pandemic, with its complexity and global reach, created unprecedented challenges for public health and highlighted societal vulnerability to hazardous hot weather. In this study, we used data from a three-wave nationally representative survey of 3036 American adults to examine how the COVID-19 pandemic affected extreme heat vulnerability during the summer of 2020. We used mixed effects models to examine the roles of socio-demographic characteristics and pandemic-related factors in the distribution of negative heat effects and experiences across the United States. The survey findings show that over a quarter of the US population experienced heat-related symptoms during the summer of 2020. Mixed effects models demonstrate that among all socio-economic groups, those who were most vulnerable were women, those in low-income households, unemployed or on furlough, and people who identify as Hispanic or Latino or as other non-white census categories (including Asian, American Indian or Alaska Native, Native Hawaiian or other Pacific Islander, and multi-racial US residents). The study findings indicate that millions of people in the US had difficulty coping with or responding to extreme heat because of the direct and indirect effects of the COVID-19 pandemic. Limited access to cooling as well as COVID-19 related social isolation played a major role in adverse heat health effects. Geographically, the South and the West of the US stood out in terms of self-reported negative heat effects. Overall, the study suggests that the intersection of two health hazards—extreme heat and coronavirus SARS-CoV2—amplified existing systemic vulnerabilities and expanded the demographic range of people vulnerable to heat stress.

1. Introduction

Extreme heat is a known risk to human health. Prior research established temperature-mortality relationships (Anderson *et al* 2013, Gasparrini *et al* 2015, O'Lenick *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 (Harlan *et al* 2013, Hayden *et al* 2017, Howe *et al* 2019). In the United States, socio-economic structural inequities, rooted in history, political ecology, and governance, produce systemic vulnerabilities to extreme heat, especially in low-income communities, among the elderly, people of color, ethnic minorities, and socially isolated individuals without access to cooling (Klinenberg 2002, Wilhelmi and Hayden 2010, Tierney 2014, Bao *et al* 2015, O'Lenick *et al* 2019, Thomas *et al* 2020). Energy poverty is one of the factors driving extreme heat vulnerability, with unemployed, low-income, African American and Hispanic/Latino residents disproportionately lacking thermal comfort in their homes (Hayden *et al* 2011, 2017, Baniassadi *et al* 2020, Bednar and Reames 2020). In an effort to help the most vulnerable populations, local governments have implemented extreme heat response measures at the community level that range from establishing designated cooling centers (Berisha *et al* 2017)

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to developing community-based programs aimed at strengthening social networks (Ebi and Semenza 2008).

The COVID-19 pandemic disrupted many safety nets that had been put in place to cope with and respond to extreme heat in the United States (US). In the early days of the pandemic, government policies focused on reducing SARS-CoV2 transmission and contact among individuals included issuing stay-at-home orders, and closing businesses, public buildings and gathering places (Philpot *et al* 2021). These necessary actions were effective in slowing the coronavirus transmission and saving lives (Lurie *et al* 2020, Medline *et al* 2020, Padalabalanarayanan *et al* 2020). However, they limited access to cooling centers, significantly decreased human face-to-face interactions, an important aspect of social capital (Kent *et al* 2019), and resulted in an economic downturn across the US (del Rio-Chanona *et al* 2020).

In early 2020, there was a growing concern that the COVID-19 pandemic, and the associated impacts on health, economy, and lifestyles, could prompt changes in the population's heat-protective behaviors and coping capacity that could further exacerbate vulnerability to heat stress. Research published during the course of the 1st year of the COVID-19 pandemic emphasized the compounding risks of climate extremes and COVID-19 (Phillips *et al* 2020) and highlighted social vulnerability, health inequity, and individual agency as important determinants of health (Dasgupta *et al* 2020, Thomas *et al* 2020, Freese *et al* 2021). Racial disparities were noted, as higher numbers of COVID-19 cases were documented among Black or African American, Hispanic/Latino and Native American populations (Hooper *et al* 2020, Yellow Horse *et al* 2021). Martinez *et al* (2020) discussed the importance of government preparedness designed to protect the population from the intersection of extreme heat and COVID-19 and emphasized that social distancing and space use restrictions could hinder efforts to provide cooling protection to the most vulnerable, and that social and health care systems were likely to be overwhelmed.

Ongoing research illustrates how the COVID-19 pandemic intersects with social vulnerability (Karaye and Horney 2020, Morabito *et al* 2020, Snyder and Parks 2020). While it is becoming evident that the pandemic had an effect on the population vulnerable to weather hazards, we lack specific knowledge whether the COVID-19 pandemic had amplified or alleviated existing heat vulnerabilities and what broader socio-demographic and pandemic-related factors contributed to these changes. To begin addressing these knowledge gaps, this article examines how aspects of vulnerability intersected with the COVID-19 pandemic and how the combined effect of systemic social vulnerabilities and pandemic-related factors contributed to extreme heat risk throughout the summer of 2020 across the US. Specifically, this article (a) quantifies the self-reported impacts of extreme heat on the US population during the COVID-19 pandemic, (b) examines geographic and socio-demographic predictors of negative heat effects, and (c) explicitly assesses the added effect of the pandemic on heat risk.

2. Methods

2.1. Data collection

In June 2020, when this study began, little was known about how the COVID-19 pandemic would unfold and how its evolution would impact the health of the US population and economy. A three-wave cross-sectional nationally representative survey of 3036 American adults aged 18 and older was conducted in July–September 2020 and included respondents from every state and the District of Columbia (figure 1). Administering a survey to the US population at different time-points in the pandemic and throughout the hottest months of the summer allowed us to understand how heat experiences and behaviors may have shifted temporally in response to population experiences with the COVID-19 pandemic, alongside exposure to varying weather extremes across the warm season.

All questionnaires were self-administered by respondents in a web-based environment. The sample was part of the Ipsos KnowledgePanel® Omnibus, an online panel recruited using probability-based sampling methods. The KnowledgePanel is one of the few high-quality national probability-based online panels operating in the US, and it produces results projectable to the American general population with a known margin of error. Panel members were recruited using address-based probability sampling; those without internet access were provided an internet-enabled device. The data are weighted by key demographic variables to match US Census Bureau statistics. Weights are constructed using age, race/ethnicity, gender, education, Census region, income, metropolitan vs non-metropolitan location, home ownership, and internet access. Different respondents participated in each wave, and for each wave of data collection, the average margin of error is ±3 percentage points at the 95% confidence level. Each wave of the survey is generalizable to the US population.

The survey included 18 questions about COVID-19 and extreme heat risk perceptions, experiences, self-reported symptoms of heat stress and COVID-19, household coping capacity (e.g. using an air-conditioner to cool their home), self-efficacy, and protective behaviors (e.g. changing their routines to avoid the outdoors during the hottest parts of the day or reducing strenuous physical activity), as well as the

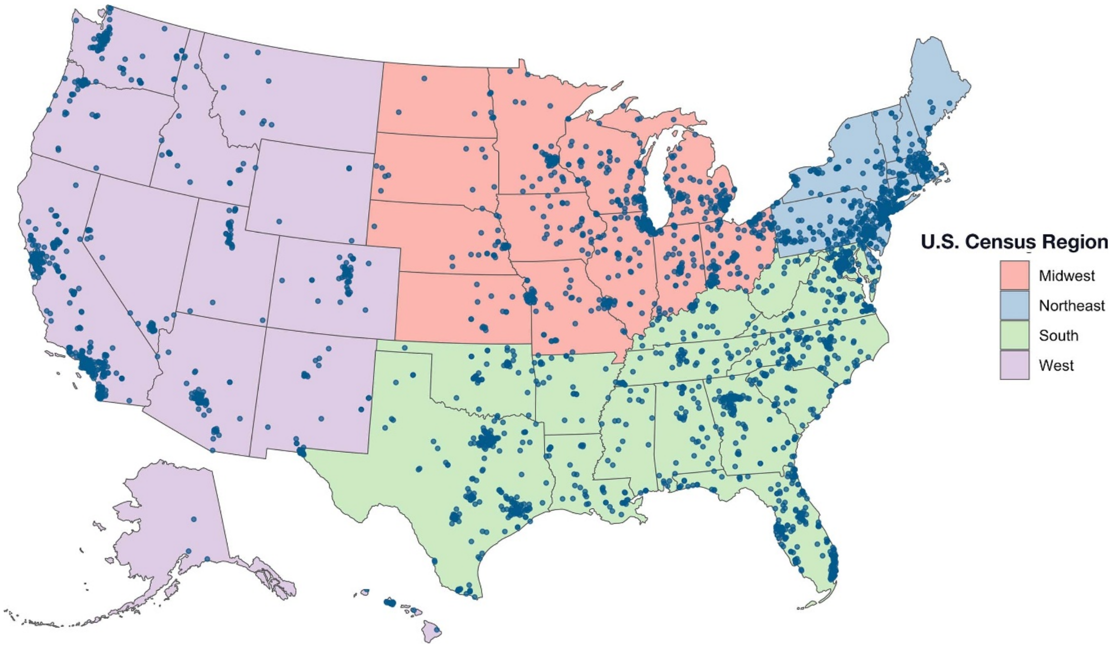

Figure 1. Locations of 3036 respondents who participated in the surveys conducted in July–September 2020.

challenges of taking protective actions from heat during the COVID-19 pandemic (Wilhelmi *et al* 2020; supplementary file (available online at stacks.iop.org/ERL/16/084060/mmedia)). In this article, we report on a subset of the survey questions.

2.2. Data analysis

Survey data were processed using R statistical software for quantitative data analyses. Frequency analyses were conducted to provide descriptions of demographic characteristics and quantify participants' responses to survey questions. We used mixed-effects logistic regression and mixed effects linear regression using the lme4 package in R to estimate associations between selected predictor and outcome variables derived from survey responses (e.g. self-reported negative heat experiences). For each outcome variable we fit two models: (a) a base model with geographic and sociodemographic predictors; and (b) a model that added transient COVID-19 pandemic-related effects experienced during 2020 to the base model's set of predictors. For all models, we estimated odds ratios (ORs) or regression coefficients and 95% confidence intervals (CIs). To estimate statistical significance of our predictor variables, we compared the fit of models with and without each variable using a likelihood ratio test (LRT). For each variable, LRT results with p-values of $\leqslant 0.05$ were considered statistically significant; in other words, we considered that variable to significantly improve overall model fit. For variables significant at $p \leqslant 0.05$ we also interpreted the effect size and direction of each variable: an OR $>$ 1.0 is indicative of a positive association, while an OR $<$ 1.0 is indicative of a negative association. Outcome variables included responses to questions asking whether the respondent (a) experienced any heat-related symptoms during the 2020 summer (yes/no), (b) felt too hot at home during the 2020 summer (yes/no), or (c) reported decreased productivity while working during the 2020 summer (yes/no). We also modeled two additional outcome variables that were included as predictors in the other models: (d) access to home air conditioning (AC), and (e) an index of social isolation related to the COVID-19 pandemic.

2.2.1. Base model

Explanatory variables used in the base model were chosen based on literature findings and expert knowledge, and represented respondent geographic location, sociodemographic status, and adaptive capacity (e.g. AC access). Base model variables included geographic region (using the four US Census Bureau regions), living within or outside a metropolitan statistical area, age group (18–24; 25–34; 35–44; 45–54; 55–64; 65–74; 75+ years), gender (male; female), race/ethnicity (Hispanic or Latino/a; White, non-Hispanic; Black, non-Hispanic; Other or two or more races, non-Hispanic), educational attainment (less than high school; high school graduate; some college; bachelor's degree or higher), annual household income (less than \$30 000; \$30 000–\$49 999; \$50 000–\$74 999; \$75 000–\$99 999; \$100 000–\$149 000; \$150 000–\$199 000; \$200 000 or more), current employment status of the respondents (employed; unemployed or on furlough; retired; other, including student and homemaker), household characteristics (living alone, having children in the household), and access to AC. AC access was included as a categorical variable with three levels: (a) respondents with no AC access at home; (b) respondents who have AC at home but cannot or do not use it effectively due to cost or needed repairs; and (c) respondents who have AC at home and use it. Explanatory variables used in the base model were considered random effects.

2.2.2. Added effects model

The explanatory variables in the pandemic-related added effects model included binary variables indicating COVID risk perception (i.e. not worried to moderately worried; very to extremely worried), loss of employment (yes/no), loss of income from a job or business (yes/no), became responsible for childcare or home schooling (yes/no), inability to get adequate medical care (yes/no), increased difficulty leaving home and going to an air conditioned place (yes/no), increased difficulty with regard to changing one's daily routine to avoid extreme heat (yes/no), and an ordinal variable (0–6) to capture the degree of pandemic-related social isolation experienced by respondents. A variable representing the degree of pandemic-related social isolation was created by summing binary responses (yes = 1; no = 0) for the following situations since 1 March 2020: (a) respondent had been unable to visit with family/friends, (b) respondent was isolated at home alone; (c) respondent never left home for shopping, errands, etc; (d) respondent self-isolated to protect him/herself from COVID-19; (e) respondent indicated that it was more difficult for him/her to check on family; and (f) respondent indicated that it was more difficult for family to check on him/her. Thus, the social isolation index (table 1) is a categorical variable of increasing severity. A zero on the scale would indicate someone who experienced no pandemic related social isolation. The survey responses included in the social isolation index were informed by prior research on extreme heat vulnerability and the role of social networks in mediating heat health effects (Klinenberg 2002, Hayden *et al* 2011, 2017, Kafeety *et al* 2020). Social isolation represents a disconnectedness from social networks, including support from friends and family and community resources for health protection (Kafeety *et al* 2020). Pandemic-related explanatory variables were considered fixed effects.

3. Results

3.1. Descriptive results

Table 1 summarizes demographic characteristics and responses from 3036 respondents, including weighted and unweighted results. In this US-based study during the summer of 2020, more than a quarter of the US population[4] (27.8%) reported having one or more symptoms that they believed were related to extreme heat. When responding about self-reported heat-related symptoms, the participants could select any of the following: headache, rapid heartbeat, nausea or vomiting, muscle pain or cramps, heavy sweating during intense exercise, dizziness, fainting, confusion, and cold, pale and clammy skin (supplementary file). While a majority of the respondents did not experience heat stress at home, 14.7% reported feeling too hot at home in 2020, and 12.5% had decreased productivity while working during very hot weather. Nearly one-third of the US population expressed some degree of worry about heat when they were at work. This indicates that heat exposure can be an issue for both indoor and outdoor occupations with 5% working outdoors, 4% working indoors (away from home) without AC and 23% working at home in March–September 2020 (Wilhelmi *et al* 2020).

While a majority of US residents had AC in their homes and were able to use it, over a quarter (25.8%) of the population either did not have AC (5.5%) or had AC but could not cool their homes effectively for a number of reasons (20.3%). The main factors that reduced people's ability to cool their homes effectively included the high cost of electricity (13.6%) and an attempt to save energy (13%).

When asked about the effects of the COVID-19 pandemic on social face-to-face interactions, 75% indicated at least one change in behavior contributing to social isolation. Findings from this nationally representative survey showed that one-half of the US adult population (51%) had been unable to visit with family/friends. Many Americans indicated that it was more difficult during the summer of 2020, compared to a normal summer, to check on family and friends (22%) or for family to check on him/her (15.2%). Over a quarter (28.8%) reported being isolated at home alone. Specifically, to protect themselves from COVID-19, 14.8% reported self-isolating or never leaving home for shopping or other errands (5.4%) (Wilhelmi *et al* 2020).

3.2. Factors associated with negative heat effects

3.2.1. Heat symptoms

The results from the base sociodemographic model showed that household income, age, race/ethnicity, access to AC, and geographic region exhibited significant association with variation in reporting heat health symptoms (figure 2(a)). Holding other variables constant, those with the lowest household incomes (less than \$30 000 per year; OR = 1.26, 95% CI = 1.01–1.59) were 68% more likely to experience at least one heat-related health symptom than those with the highest household incomes (greater than \$200 000 per year; OR = 0.75, 95% CI = 0.58–0.97). By age, people who were more likely to experience heat-related symptoms were in the youngest (18–24; OR = 1.25, 95% CI = 0.90–1.74) and middle age

[4] US residents age 18 and over.

Table 1. Frequency counts and percentages (weighted and unweighted) of explanatory and outcome variables. Weighted counts rounded to the nearest whole number.

Variable	Values	Un-weighted Count (%)	Weighted Count (%)	Missing Count (%)
Gender	Male	1563 (51.5%)	1452 (48.4%)	0 (0.0%)
	Female	1473 (48.5%)	1548 (51.6%)	
Age group	18–24 years	255 (8.4%)	343 (11.4%)	0 (0.0%)
	25–34 years	501 (16.5%)	540 (18.0%)	
	35–44 years	516 (17.0%)	497 (16.6%)	
	45–54 years	455 (15.0%)	393 (13.1%)	
	55–64 years	648 (21.3%)	588 (19.6%)	
	65–74 years	452 (14.9%)	433 (14.4%)	
	75+ years	209 (6.9%)	206 (6.9%)	
Race/ethnicity	White, non-Hispanic	2153 (70.9%)	1896 (63.2%)	0 (0.0%)
	Black, non-Hispanic	292 (9.6%)	354 (11.8%)	
	Other or 2+ races, non-Hispanic	247 (8.1%)	258 (8.6%)	
	Hispanic or Latino/a	344 (11.3%)	492 (16.4%)	
Income	Less than $30 000	437 (14.4%)	522 (17.4%)	0 (0.0%)
	$30 000–$49 999	401 (13.2%)	429 (14.3%)	
	$50 000–$74 999	524 (17.3%)	516 (17.2%)	
	$75 000–$99 999	451 (14.9%)	416 (13.9%)	
	$100 000–$149 999	567 (18.7%)	495 (16.5%)	
	$150 000–$199 999	361 (11.9%)	350 (11.7%)	
	$200 000 or more	295 (9.7%)	272 (9.1%)	
Educational attainment	Less than high school	194 (6.4%)	318 (10.6%)	0 (0.0%)
	High school	806 (26.5%)	849 (28.3%)	
	Some college	833 (27.4%)	834 (27.8%)	
	Bachelor's degree or higher	1203 (39.6%)	999 (33.3%)	
Region	Northeast	547 (18.0%)	525 (17.5%)	0 (0.0%)
	Midwest	695 (22.9%)	624 (20.8%)	
	South	1112 (36.6%)	1137 (37.9%)	
	West	682 (22.5%)	714 (23.8%)	
Residence in an metropolitan statistical area	Non-metro area	416 (13.7%)	378 (12.6%)	0 (0.0%)
	Metro area	2620 (86.3%)	2622 (87.4%)	
AC	Does not have AC	166 (5.5%)	166 (5.6%)	23 (0.8%)
	Has AC and uses it	2235 (74.2%)	2158 (72.6%)	
	Has AC, but cannot cool home effectively	612 (20.3%)	648 (21.8%)	
Children	No children in household	2221 (73.2%)	2179 (72.6%)	0 (0.0%)
	One or more children	815 (26.8%)	821 (27.4%)	
Employment status	Employed full-time or par	1736 (57.2%)	1622 (54.0%)	0 (0.0%)
	Unemployed or on furlough	179 (5.9%)	195 (6.5%)	
	Retired	683 (22.5%)	659 (22.0%)	
	Other (student, homemaker)	438 (14.4%)	524 (17.5%)	
Live alone	Does not live alone	2386 (78.6%)	2355 (78.5%)	0 (0.0%)
	Lives alone	650 (21.4%)	645 (21.5%)	
Social isolation index	0	758 (25.0%)	739 (24.6%)	0 (0.0%)
	1	1063 (35.0%)	1041 (34.7%)	
	2	674 (22.2%)	665 (22.2%)	
	3	336 (11.1%)	346 (11.5%)	
	4	150 (4.9%)	150 (5.0%)	
	5	48 (1.6%)	53 (1.8%)	
	6	7 (0.2%)	7 (0.2%)	
COVID risk perception	Not to moderately worried	1972 (65.2%)	1879 (62.9%)	11 (0.4%)
	Very or extremely worried	1053 (34.8%)	1108 (37.1%)	
Lost income during pandemic	Has not lost income	2265 (74.6%)	2245 (74.9%)	0 (0.0%)
	Lost income	771 (25.4%)	755 (25.1%)	
Lost job during pandemic	Has not lost job	2679 (88.2%)	2631 (87.7%)	0 (0.0%)
	Lost job	357 (11.8%)	369 (12.3%)	

(Continued.)

Table 1. (Continued.)

Variable	Values	Un-weighted Count (%)	Weighted Count (%)	Missing Count (%)
Childcare	Has not become responsible	2398 (79.0%)	2370 (79.0%)	0 (0.0%)
	Became responsible for children or home schooling	638 (21.0%)	630 (12.0%)	
AC access	Has AC and uses it	2235 (74.2%)	2158 (72.6%)	23 (0.8%)
	Does not have AC or has AC but does not use it effectively due to cost or needed repairs	778 (25.8%)	814 (27.4%)	
Inadequate medical care during pandemic	No	2744 (90.4%)	2707 (90.2%)	0 (0.0%)
	Been unable to get adequate care	292 (9.6%)	293 (9.8%)	
Ability to leave home during pandemic	No different or less difficult	2251 (74.1%)	2202 (73.4%)	0 (0.0%)
	More difficult this summer	785 (25.9%)	798 (26.6%)	
Ability to change routine during pandemic	No different or less difficult	2451 (80.7%)	2375 (79.2%)	0 (0.0%)
	More difficult this summer	585 (19.3%)	625 (20.8%)	
Experienced heat-related health symptoms	No	2178 (72.2%)	2138 (71.9%)	17 (0.6%)
	Yes	837 (27.8%)	838 (28.1%)	
Felt too hot at home	No	2575 (85.3%)	2537 (85.1%)	17 (0.6%)
	Yes	444 (14.7%)	444 (14.9%)	
Decreased productivity while working due to heat	No	2643 (87.5%)	2626 (88.1%)	17 (0.6%)
	Yes	376 (12.5%)	355 (11.9%)	

groups (35–44; OR = 1.34, 95% CI = 1.00–1.81). By race/ethnicity, Hispanic/Latino respondents were most likely to report experiencing heat symptoms (OR = 1.27, 95% CI = 0.97–1.67). AC access was also strongly associated with heat symptoms. Those who had AC at home but reported barriers to using it (including cost, ineffective equipment, or needing repairs) were the most likely to report having heat symptoms (OR = 1.46, 95% CI = 1.02–2.09), a rate 125% higher than those who had AC at home and reported no barriers to using it (OR = 0.65, 95% CI = 0.46–0.91). By region, people in the South were the most likely to report heat symptoms (OR = 1.17, 95% CI = 0.99–1.38). Combining all significant demographic factors, the group estimated to have the highest chance of reporting heat symptoms (at 60%, 33 percentage points higher than the national average reported in table 1) were Hispanic/Latino residents in the South, 35–44 years old, who were earning less than $30 000 per year and had AC but could not use it effectively.

The model adding COVID-19 pandemic-related effects explained significant additional variation in reporting heat-related health symptoms (figure 2(b)). The following factors were significant in predicting heat-related symptoms: pandemic-related social isolation (OR = 1.09, 95% CI = 1.01–1.18), worrying about COVID-19 (very worried or extremely worried; OR = 1.24, 95% CI = 1.03–1.50), losing income from a job or business (OR = 1.39; 95% CI = 1.11–1.74), and experiencing more difficulty in changing daily routines to avoid extreme heat, compared to a normal summer (OR = 1.71, 95% CI = 1.37–2.13).

3.2.2. Feeling too hot at home

Across sociodemographic factors in the base model associated with feeling too hot at home during the summer of 2020, significant positive predictors included living in the West (OR = 1.45, 95% CI = 1.04–2.03). Not having AC (OR = 2.13, 95% CI = 1.21–3.76) or having AC but not being able to use it effectively to cool one's home (OR = 1.40, 95% CI = 0.84–2.34), were the strongest predictors of thermal discomfort indoors at home (figure 3(a)). Combining all significant demographic factors, the group estimated to have the highest chance of feeling too hot while indoors at home (at 47%, 32 percentage points higher than the national average) were women in the West who did not have AC at home.

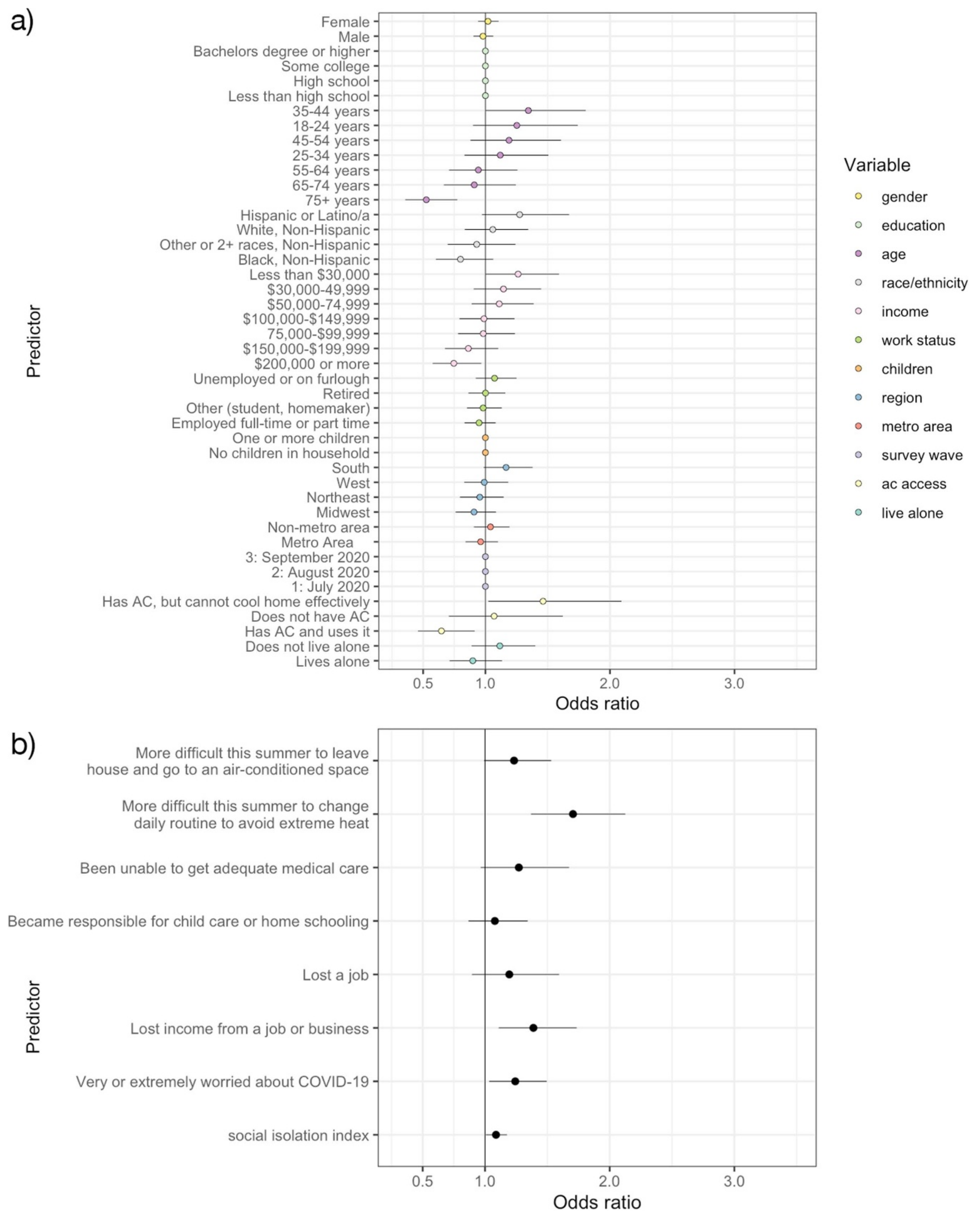

Figure 2. Predictors of self-reported heat symptoms; (a) predictors associated with demographic, geographic, and socio-economic characteristics; (b) predictors associated with pandemic-related impacts. Error bars indicate 95% CIs.

The model adding COVID-19 pandemic effects also showed significant variation in reporting feeling too hot at home in summer 2020. Participants who reported feeling too hot also reported difficulty leaving the house to go to an air-conditioned place (OR = 1.82, 95% CI = 1.40–2.37), changing daily routines to avoid heat (OR = 1.39, 95% CI = 1.06–1.82), and getting adequate medical care, compared to a normal summer (OR = 1.65, 95% CI = 1.17–2.23). Pandemic-related social isolation (OR = 1.11, 95% CI = 1.01–1.23), and worrying about COVID-19 (very worried or extremely worried; OR = 1.49, 95% CI = 1.18–1.89) were also associated with feeling too hot while at home.

3.2.3. Decreased productivity at work

The sociodemographic factors in the base model associated with significant variation in decreased productivity (figure 4(a)) included: having AC but not being able to cool one's home effectively (OR = 1.50, 95% CI = 0.93–2.39), race/ethnicity (Other or 2+ races, non-Hispanic; (OR = 1.4, 95% CI = 0.92–2.13). Work status, regardless of whether people were employed; (OR = 1.25, 95% CI = 0.89–1.76)

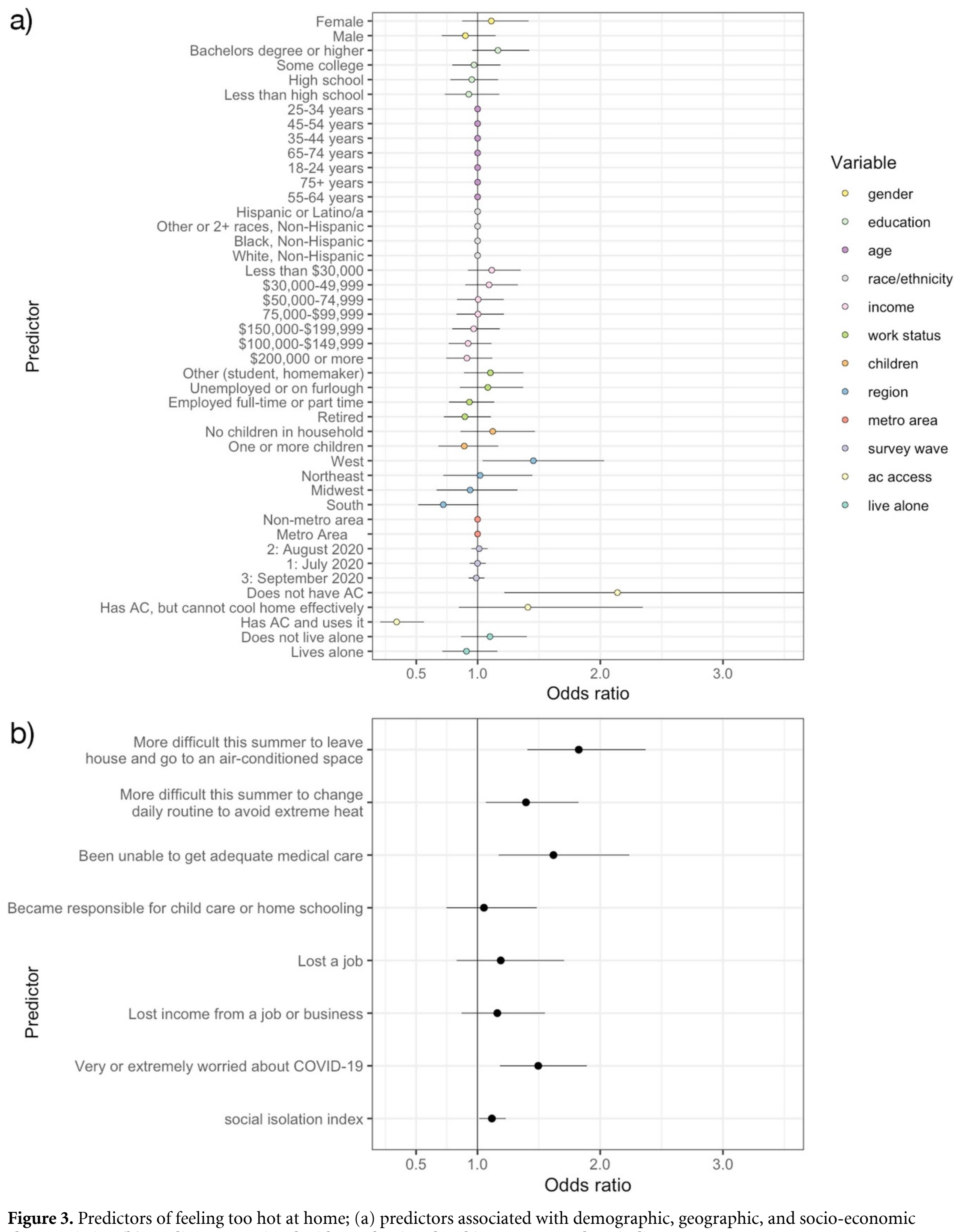

Figure 3. Predictors of feeling too hot at home; (a) predictors associated with demographic, geographic, and socio-economic characteristics; (b) predictors associated with pandemic-related impacts. Error bars indicate 95% CIs.

or unemployed (OR = 1.31, 95% CI = 0.86–1.99) was also significant. Combining all significant demographic factors, the group estimated to have the highest chance of reporting decreased productivity (at 28%, 16 percentage points higher than the national average reported in table 1) were people in the 'Other or two or more races, non-Hispanic' race/ethnicity category living in the West who were unemployed or on furlough and had AC but were not able to use it to cool their home effectively.

The model adding COVID-19 pandemic-related effects explained significant additional variation in reduced productivity while working (figure 4(b)). Experiencing more difficulty in changing daily routines to avoid extreme heat compared to a normal summer (OR = 1.61, 95% CI = 1.21–2.13) and experiencing more difficulty in getting adequate medical care compared to a normal summer (OR = 1.45, 95% CI = 1.04–2.03) were significant in predicting reduced productivity.

3.3. Factors associated with access to cooling

We also modeled factors associated with lack of access to effective air conditioning at home during summer

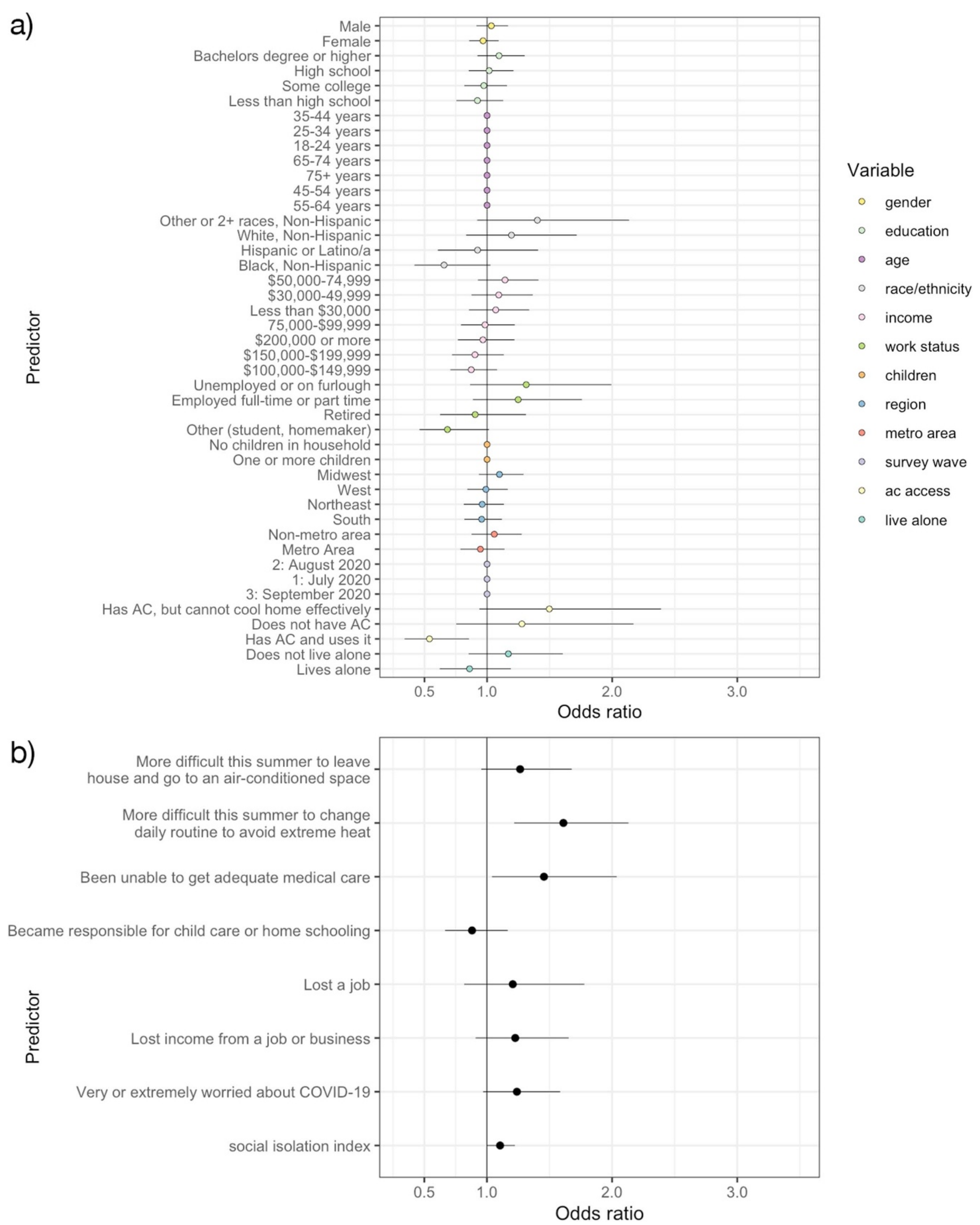

Figure 4. Predictors of decreased productivity when working during very hot weather: (a) predictors associated with demographic, geographic, and socio-economic characteristics; (b) predictors associated with pandemic-related impacts. Error bars indicate 95% CIs.

2020. Those without access to effective cooling at home were more likely to live in the Western region of the country (OR = 1.74, 95% CI = 1.23–2.47). Financial constraints played a major role: those who were unemployed or on furlough (OR = 1.60, 95% CI = 1.078–2.50) or had jobs with an annual income of less than $30 000 (OR = 1.14, 95% CI = 0.81–1.56) reported reduced ability to use AC. Women were more likely than men to report barriers to effectively cooling their homes (OR = 1.1, 95% CI = 0.90–1.40) (figure 5(a)). Combining all significant demographic factors, the group estimated to have the highest chance of reporting barriers to AC access (at 72%, 46 percentage points higher than the national average reported in table 1) were people 25–34 years old in the 'Other or two or more races, non-Hispanic' race/ethnicity category living in the West with household incomes less than $30 000 per year.

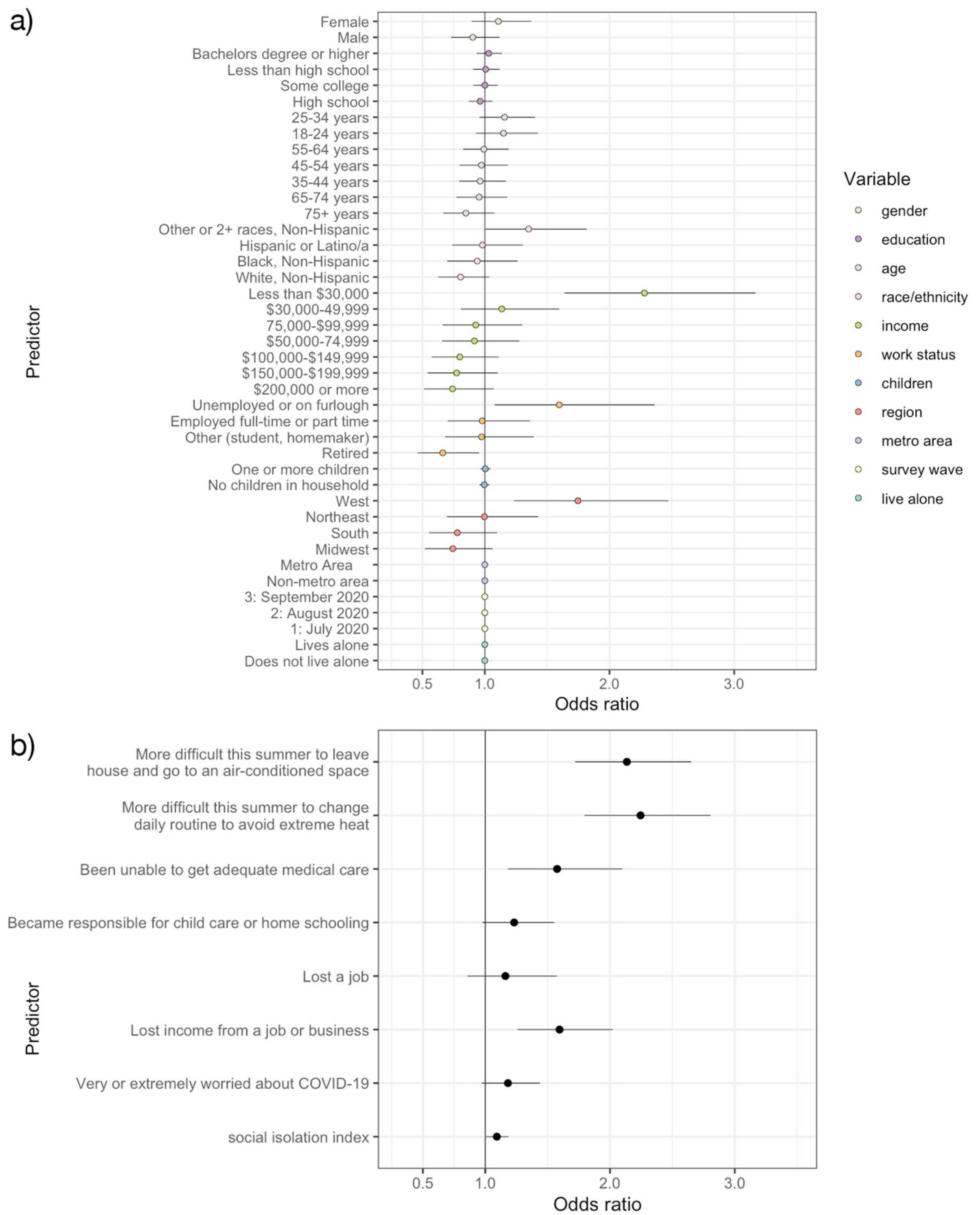

Figure 5. Predictors of reduced ability to use air conditioning to effectively cool homes; (a) predictors associated with demographic, geographic, and socio-economic characteristics; (b) predictors associated with pandemic-related impacts. Error bars indicate 95% CIs.

The COVID-19 pandemic further decreased people's capacity to use AC. The model adding COVID-19 pandemic-related effects explained significant additional variation in reporting reduced ability to use air conditioning and effectively cool homes (figure 5(b)). The following factors were significant in predicting barriers to using AC: social isolation (OR = 1.09, 95% CI = 1.01–1.18), losing income from a job or business (OR = 1.59; 95% CI = 1.26–2.02), experiencing more difficulty in changing daily routines to avoid extreme heat compared to a normal summer (OR = 2.24, 95% CI = 1.79–2.80), experiencing more difficulty getting adequate medical care compared to a normal summer (OR = 1.57, 95% CI = 1.18–2.10), and experiencing more difficulty leaving home and going to an AC place (OR = 2.13, 95% CI = 1.72–2.65).

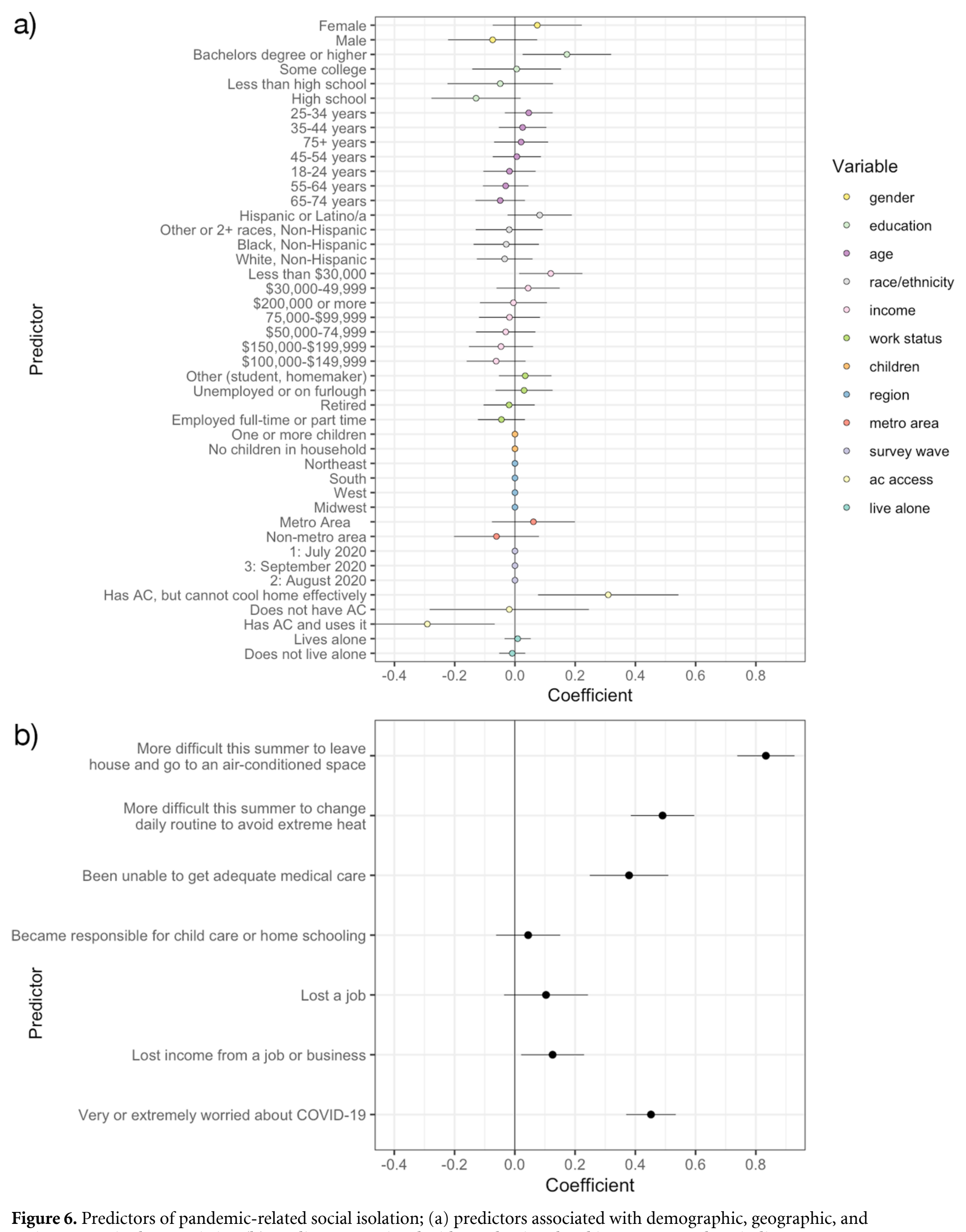

Figure 6. Predictors of pandemic-related social isolation; (a) predictors associated with demographic, geographic, and socio-economic characteristics; (b) predictors associated with pandemic-related impacts. Error bars indicate 95% CIs.

3.4. Factors associated with pandemic-related social isolation

Across factors in the base sociodemographic model, those that exhibited significant association with variation in reporting social isolation, a known risk factor for negative heat-related effects, were being female (regression coefficient $b = 0.07$, 95% CI = −0.07–0.22), having a bachelor's degree or higher education ($b = 0.17$, 95% CI = 0.03–0.32), and having AC but not being able to use it effectively ($b = 0.31$, 95% CI = 0.08–0.54) (figure 6(a)). Combining all significant demographic factors, the group estimated to have the highest reported pandemic-related social isolation (at 2.2 on a scale of 0–6, 0.8 points higher than the national average) were women with a bachelor's degree or higher, who have AC but are not able to use it effectively.

The model adding COVID-19 pandemic-related effects explained significant additional variation in reporting behaviors that contributed to social isolation (figure 6(b)). The following factors were significant in predicting social isolation: worrying about COVID-19 (very worried or extremely worried; $b = 0.45$, 95% CI = 0.36–0.53), experiencing more difficulty in changing daily routine to avoid extreme heat ($b = 0.49$, 95% CI = 0.38–0.59), experiencing more difficulty to get adequate medical care ($b = 0.38$, 95% CI = 0.25–0.50), losing income from a job or business ($b = 0.12$, 95% CI = 0.02–0.22), and having difficulty leaving the house to go to an air conditioned space ($b = 0.83$, 95% CI = 0.04–0.92).

4. Discussion

Summarizing the mixed effects model results and the tests for significance, it is evident that among all socio-economic groups, those who were most vulnerable were women, those in low-income households, unemployed or on furlough, Hispanic or Latino and mixed-race Americans (table 2). Geographically, the South and the West of the US stood out in terms of self-reported negative heat effects. It is also evident that access to cooling and affordable AC played a key role, as well as COVID-19 pandemic-related factors, including social isolation. Our survey showed that millions of people in the US had difficulty coping with or responding to extreme heat because of the direct and indirect effects of the COVID-19 pandemic. Key factors that contributed to increased heat risk and decreased coping capacity during the time of COVID-19 were (a) limited or reduced household resources, preventing access to cooling and (b) pandemic-related social isolation, reducing social capital and access to available community resources.

Our survey results mirror the dire economic picture across the US during the pandemic as concurrent medical and economic crises unfolded (Susskind and Vines 2020, Ibn-Mohammed *et al* 2021). We found that the ability to cool homes effectively proved to be difficult for millions of US residents, especially those who have low incomes and those who reported losing income, jobs or being placed on furlough since the beginning of the pandemic. While energy poverty is a persistent problem in the US, the COVID-19 pandemic exacerbated socio-economic inequities and demonstrated how the dependence on mechanical air conditioning during an economic crisis can place more people in the US at risk from extreme heat. It also provided an opportunity to re-evaluate the progress towards more sustainable and resilient approaches to heat adaptation. With a changing climate, and current trends in US construction practices and energy codes lacking progress towards passive survivability of typical residential buildings (Baniassadi *et al* 2020), there is an even greater need for the reevaluation of inequitable energy burdens in the US and inclusion of energy justice in the climate adaptation efforts.

Despite early warnings of heightened risk at the intersection of COVID-19 and extreme weather events, and years of scholarly research on the intersection of disasters and health inequities, health and hazards response systems in the United States were overwhelmed by the intersection of SARS-CoV2 and extreme heat. These compound hazard events magnified existing social vulnerabilities and reduced the capacity of governments to respond effectively to protect the population from heat hazards, particularly in communities that are historically less resilient (Zscheischler *et al* 2018, Gaynor and Wilson 2020). At a community level, reliance on public spaces to provide cooling shelters for those in need was challenged by social distancing measures as traditional sources of cooling such as libraries may have been inaccessible in many cities due to COVID-19 closures. As a result, millions of people in the US found it more difficult, compared to a normal summer, to seek medical care, and/or leave home and go to an air conditioned place (such as a cooling center).

The summer of 2020 marked the 25th anniversary of the deadly Chicago heat wave, which illustrated the importance of social capital in reducing negative heat-health outcomes (Klinenberg 2002). The safety nets in the form of social networks that connect vulnerable individuals to their neighbors or community resources have been helpful coping and response mechanisms to extreme heat in many communities (Yardley *et al* 2011, Kafeety *et al* 2020). These safety nets have been disrupted by the COVID-19 pandemic with millions of people being isolated at home alone and finding it more difficult to check on friends and neighbors. In addition to worry about COVID-19, health-care seeking behavior was initially altered as early messages discouraged people from seeking medical attention unless they were acutely ill because of concern that health-care facilities would be overburdened (Lange *et al* 2020).

The associations between worrying about COVID-19 and experiencing heat-related symptoms or feeling too hot at home, in part can be explained by spending more time at home. Many US residents were worried about COVID-19 and adhered to 'stay at home' orders. While this was a protective action against COVID-19, it may have placed people at risk for extreme heat exposure, particularly if their AC was not cooling efficiently, if cooling centers were closed in response to COVID-19, and/or if people were reluctant to ask for help or to seek medical care at an emergency room because they were worried about COVID-19 exposure. Prior research also suggests that social isolation-induced anxiety can reduce one's coping ability during emergencies (Lubik and Kosatsky 2019), including a timely response to extreme heat conditions.

4.1. Limitations

This research has several limitations. First, we recognize that some of the most vulnerable populations to both heat and COVID-19 may not be fully represented in our sample. This rapid response study

Table 2. Outcome and dependent variables. Check marks (√) indicate significant predictors at $p < 0.05$, stars (*) show significant predictors at $p < 0.1$. Bold font indicates COVID-19 pandemic-related predictors.

	Decreased productivity at work	Feeling too hot at home	Symptoms of heat illness	AC access	Social isolation
Female		*		√	√
Age 35–44 years old			√		
Hispanic or Latino			√		
Other, 2+ races, non-Hispanic	√			√	
Household income less than $30 000			√	√	*
Bachelor degree or higher					√
Employed full time or part time	√				
Unemployed or on furlough	√			√	
US region: West		√		√	
US region: South			√		
AC access (no AC or has AC but cannot cool home effectively)	√	√	√	n/a	√
Pandemic related social isolation	*	√	√	√	**n/a**
COVID-19 worry (very or extremely worried)	*	√	√	*	√
More difficult to change daily routine to avoid heat	√	√	√	√	√
More difficult to get adequate medical care	√	√	*	√	√
More difficult to leave home and go to an AC place		√	*	√	√
Losing income from a job or business			√	√	√
Becoming responsible for child care or homeschooling				*	

relied on data collected through the Ipsos KnowledgePanel Omnibus survey, which is drawn from a national probability-based panel. Accordingly, areas with small populations, like low density rural areas, were less likely to be included in the sample. In future research designs, national probability-based panels can be supplemented with samples in the specific regions of interest or with a focus on specific vulnerable socio-demographic groups. Second, the KnowledgePanel dataset combines the US Census race categories of Asian American, American Indian/Alaska Native and Native Hawaiian/other Pacific Islander races into one other/non-Hispanic category. We found that this category was a significant predictor of reduced productivity while working, as well as lower AC access. Due to the way the demographic data were represented in our dataset, we were unable to differentiate what percentage of Asian Americans, American Indian/Alaska Native and Native Hawaiian/Other Pacific Islander populations were most affected by heat and COVID-19. Third, this study did not fully capture indoor and outdoor exposures of the survey participants. Our findings indicate that extreme heat was an issue for people with both indoor and outdoor occupations. We recognize that occupational health and heat exposure is an important issue. Due to data limitations, we were unable to differentiate specific occupations (e.g. agriculture, construction, landscaping) among the 5% of the population engaged in outdoor work. Our survey (supplemental file; Wilhelmi *et al* 2020) included questions about indoor and outdoor heat and COVID-19 risk perception which will be explored in subsequent manuscripts. Fourth, this US-based study included residents of the 50 states and DC but did not include residents of US territories.

4.2. Conclusions

Overall, the survey results show that the COVID-19 pandemic illustrated the fragility of the safety nets designed to assist those who lack cooling at home and/or are socially isolated. The data provided empirical evidence that the intersection of the COVID-19 pandemic and hot weather during the summer of 2020 exacerbated existing systemic vulnerabilities as well as health and energy inequities and reduced the capacity of millions of people in the US to cope with heat. The fragility of safety nets during the 2nd year of the ongoing COVID-19 pandemic pose a question of whether US cities are prepared for extreme heat in 2021. Because of the evolving nature of both risks, it is critical that local, state, and federal government officials ensure that those most vulnerable to both extreme heat and COVID-19 are receiving timely messages on how to best protect themselves and that they have the necessary resources to safeguard their health in a multi-hazard situation.

Data availability statement

The data generated and/or analyzed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Acknowledgments

This project is funded by National Science Foundation (NSF) Social, Behavioral and Economic Sciences/Division of Behavioral and Cognitive Sciences RAPID Award No. 2031217. National Center for Atmospheric Research (NCAR) is sponsored by the NSF.

Ethical statement

The study protocol was reviewed and approved by the NCAR/UCAR Internal Review Board (IRB No. IRB00006222).

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