"Can You Take the Heat?" Heat-Induced Health Symptoms Are Associated with Protective Behaviors

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ABSTRACT

The risks associated with extreme heat are increasing as heat waves become more frequent and severe across larger areas. As people begin to experience heat waves more often and in more places, how will individuals respond? Measuring experience with heat simply as exposure to extreme temperatures may not fully capture how people subjectively experience those temperatures or their varied impacts on human health. These impacts may also influence an individual's response to heat and motivate risk-reduction behaviors. If subjectively experiencing negative health effects from extreme heat promotes protective actions, these effects could be used alongside temperature exposure to more accurately measure extreme heat experience and inform risk prevention and communication strategies according to local community needs. Using a multilevel regression model, this study analyzes georeferenced national survey data to assess whether Americans' exposure to extreme heat and experience with its health effects are associated with self-reported protective behaviors. Subjective experience with heat-related health symptoms strongly predicted all reported protective behaviors while measured heat exposure had a much weaker influence. Risk perception was strongly associated with some behaviors. This study focuses particularly on the practice of checking on family, friends, and neighbors during a heat wave, which can be carried out by many people. For this behavior, age, race/ethnicity, gender, and income, along with subjective experience and risk perception, were important predictors. Results suggest that the subjective experience of extreme heat influences health-related behavioral responses and should therefore be considered when designing or improving local heat protection plans.

1. Introduction

Heat waves are increasing in frequency, intensity, and duration across the United States (White-Newsome et al. 2011; Vose et al. 2017). These changes in climate are expected to continue (Akompab et al. 2013; Vose et al. 2017), and populations are growing in areas most exposed to extreme heat (Jones et al. 2015). Heat waves are a serious environmental health hazard, but no universal definition or metric has emerged in the literature to classify these events (Smith et al. 2013). Instead, heat waves are often defined by absolute thresholds or relative to local climate conditions (Hawkins et al. 2017). The health effects of heat exposure vary across and within populations because of individual factors that cannot be captured by arbitrary thresholds or cutoffs (Kuras et al. 2017). Incorporating health outcomes into how heat experience is measured may inform research on the complex relationship between hazard experience and future behavior (Wachinger et al. 2013;

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Weinstein 1989). For the case of heat hazards, characterizing the subjectivity of heat-related health impacts can improve our understanding of how heat is experienced (Demuth et al. 2016; Palm and Hodgson 1992; Scolobig et al. 2012; Wei et al. 2013; Weinstein 1989). The purpose of this study is to understand how individual factors, including previous subjective experience with heat-related health symptoms, influence Americans' protective behaviors. We ask the following research questions:

1a) How does previous subjective experience with heat-related health symptoms influence protective behaviors?
1b) Is there a positive relationship between heat risk perception and protective behaviors?
2) How do these protective behaviors vary across space and among demographic groups in the United States?

We address these questions by using nationally representative georeferenced survey data from 2015 on self-reported heat-related health symptoms, risk perceptions, and protective behaviors to predict five heat-related protective behaviors with a multilevel logistic regression model. Long-term average temperatures, anomalies, and a heat wave percentile threshold (Anderson and Bell 2011; Smith et al. 2013), as well as other geographic characteristics were also tested as predictors in the model. From this study, practitioners seeking to reduce heat-related deaths can gain insight into what factors, including experience, influence individuals to be more or less likely to implement protective behaviors during extreme heat. Results could inform heat risk communication and prevention efforts to build resilience in vulnerable areas as more heat events occur.

2. Background

Current research indicates that heat waves in the United States are occurring more often, becoming more intense, and lasting longer (Akompab et al. 2013; Vose et al. 2017; Sampson et al. 2013; White-Newsome et al. 2011). The United States may be particularly vulnerable to this trend because population growth is occurring in the places most exposed to extreme heat (Jones et al. 2015). Although there is no universally accepted definition of a heat wave, it is commonly understood that these events characterize unseasonably warm or exceptionally high temperatures for an extended period and can cause negative health symptoms resulting in serious illness and death (Basu and Samet 2002; Bernard and McGeehin 2004; Harlan et al. 2014; Robinson 2001; Sampson et al. 2013; Smith et al. 2013; Whitman et al. 1997; Sarofim et al. 2016).

While heat-related mortality rates can be projected based on increased exposure under various climate scenarios (Sarofim et al. 2016; Mora et al. 2017a), these rates depend largely on the adaptability of a population. Observational studies show that mortality rates are decreasing because of adaptation (Sheridan and Allen 2018; Hondula et al. 2015) but a recent study by Guo et al. (2018) found that heat-related mortality rates in the United States are likely to increase even when accounting for adaptation measures. Heat leads to death in diverse ways that everyone can be susceptible to, even the young and healthy (Mora et al. 2017b). Extreme heat events are considered the deadliest weather-related and natural hazard in the United States (Kalkstein and Sheridan 2007; Borden and Cutter 2008). Conditions for lethal heat events are expected to increase by at least 48% worldwide by the year 2100 (Mora et al. 2017a). Clearly, there is a need to understand what promotes and impedes people from taking protective action during extremely hot weather to prevent unnecessary loss of life (CDC 2018; EPA 2006).

a. Contributing factors to heat risk

Several risk factors contribute to illness and death from extreme heat, including individual as well as contextual and environmental factors. Sociodemographic influences include age, gender, ethnicity, and socioeconomic status (Anderson and Bell 2009; Harlan et al. 2014; Klinenberg 2015; Harlan et al. 2006; Jenerette et al. 2011). Klinenberg (2015) found that social isolation and lack of community cohesion make certain individuals and groups more vulnerable to heat stress regardless of other demographic characteristics. Other factors such as acclimatization, poor cardiovascular health, poor respiratory health, and chronic illness contribute to the onset of heat-related health symptoms in the human body (Alberini et al. 2011; Browning et al. 2006; Hajat and Kosatky 2010; Hajat et al. 2010; Klinenberg 2015). Some studies also show that more people suffer heat-related health symptoms and death during the first heat wave of the warm season even if it is less severe than subsequent heat events (Anderson and Bell 2009, 2011; Liss et al. 2017). Highly developed areas with little vegetation create urban heat islands that prevent people's ability to cool down sufficiently at night as the heat continues to radiate from buildings and impervious surfaces (Clarke 1972; Harlan et al. 2014). Regardless of the context, individualized health factors and protective responses greatly determine whether someone experiences negative health effects from heat (Alberini et al. 2011; Bernard and McGeehin 2004; Hajat et al. 2010; Khare et al. 2015; Klinenberg 2015).

Despite the seriousness of this hazard, the social implications of heat waves are relatively understudied in hazards literature although heat has received more attention in public health research. Scholars emphasize that how one perceives risk influences a person's vulnerability (Jonsson and Lundgren 2015; Slovic 1987; Zografos et al. 2016; Wilhelmi and Hayden 2010; Grothmann and Patt 2005), but few studies have explored heat wave risk perceptions in the United States (Kalkstein and Sheridan 2007; Sampson et al. 2013; Semenza et al. 2008; Sheridan 2007). Few, if any, studies explicitly explore the impact that experience with heat-related health symptoms may have on protective behaviors in future heat events in the United States. Physical exposure to a hazard influences one's risk (Basu and Samet 2002; Zografos et al. 2016), even one's perception of that risk (Demski et al. 2017; Howe et al. 2013; Kalkstein and Sheridan 2007), and, depending on the hazard, may or may not influence future response (Dillon et al. 2014, 2011; Lindell and Perry 2000; Silver and Andrey 2014; Sorenson 2000; Zografos et al. 2016; Norris et al. 1999). However, differences in the relationship between personal experience and behavior have not received substantial attention; in other words, different people may respond differently to the same heat exposure.

b. *Evolution of the experience–behavior hypothesis*

Although many studies have concluded that prior experience either does not have a significant influence on protective behavior or that its influence is mixed (Demuth et al. 2016; Palm and Hodgson 1992; Scolobig et al. 2012; Wei et al. 2013; Weinstein 1989), scholars have approached the measurement of these variables differently with varying results (Becker et al. 2017; Demuth et al. 2016; Lindell and Perry 2012; Mishra and Mazumdar 2015; Mishra and Suar 2007; Mulilis et al. 2003; Norris et al. 1999; Siegrist and Gutscher 2006, 2008; Stumpf et al. 2017; Zaalberg et al. 2009). Weinstein (1989) noted several contradictory findings for various hazards, partly attributable to diverse methodological and measurement issues that may explain conflicting results, which has also been found in subsequent studies (Mishra and Mazumdar 2015; Sharma and Patt 2012; Zaalberg et al. 2009). For example, experience and protective behaviors are often operationalized as dichotomous variables, when in reality several types and ranges of experience and behavior may exist and can manifest in various ways (Demuth et al. 2016; Mishra and Mazumdar 2015; Mishra and Suar 2007; Sharma and Patt 2012; Zaalberg et al. 2009). Limiting experience or behavior to one measurement can restrict our ability to understand the nature and complexity of the relationship (Becker et al. 2017; Demuth 2015; Demuth et al. 2016; Lindell and Hwang 2008; Sharma and Patt 2012; Zaalberg et al. 2009). Some argue that the question should not be *whether* experience influences behavior but instead *how* it may influence behavior (Demuth et al. 2016; Zaalberg et al. 2009).

Dillon et al. (2014, 2011) explain the contextual importance of prior experience by defining the effect of "near miss" events on future preparedness. Their findings and others (Sharma and Patt 2012) show that prior experience is not predictive of protective action unless it is evaluated in terms of its negative impacts on that person. The same concepts can be applied to contextual experiences of heat. Unless heat experience is evaluated in the context of negative *health* impacts, prior experience of extreme temperature exposure alone may not be an effective indicator of protective action.

The question of *how* experience influences protective actions can be partly understood by focusing on mediators between experience and behavior (Wachinger et al. 2013). For example, risk perception has been found to influence the relationship between prior experience and adaptive behaviors (Becker et al. 2017; Demuth 2015; Demuth et al. 2012; Jackson 1981; Lindell and Perry 2012; Mishra and Suar 2007; Mishra et al. 2009; Norris et al. 1999; Siegrist and Gutscher 2008; Zaalberg et al. 2009; Wachinger et al. 2013). Risk perception can mediate prior experience and protective behavior through a "risk perception paradox" that is created when either 1) the benefits of taking the risk are perceived to outweigh the likelihood and extent of the costs, 2) personal responsibility to prevent losses has been shifted to another party, or 3) there is a lack of resources to implement the protective actions (Wachinger et al. 2013). In such cases, the relationship between risk perception and protective behaviors is controversial, unclear, and cannot be assumed to be highly positively correlated. When variables such as risk perception are controlled, hazard experience can have substantial (Becker et al. 2017; Wei et al. 2013), lasting, and pervasive effects on behavior (Norris et al. 1999; Demuth et al. 2016). As the specific relationship between heat risk perception and heat-health behaviors is not yet established in the literature, this study controls for risk perception as a first step in analyzing how its influence may affect the heat-health symptoms experience.

c. *Broadening the heat experience definition*

Heat stress can be inferred from ambient temperature, heat index, or other related metrics like wet-bulb globe temperature (WBGT). Although these metrics measure some level of exposure, they do not explain how any given individual's body will respond to heat or their own subjective experience of the phenomenon (Anderson and Bell 2009; Bell et al. 2008). Several components create one's heat experience (Kuras et al. 2017, 2015). Just as experience is varied and multifaceted for other hazards, it is likewise complex for heat because of its direct impact on personal health. Few heat risk studies have attempted to define heat experience by including measures of subjective heat-health impacts alongside temperature exposure. One exception is a study by Mishra and Suar (2007), that measured heat wave severity with questions related to personal and secondary experience with heat-health consequences, which directly influenced how participants prepare for future heat.

Although heat-related illness and death are preventable (CDC 2018; EPA 2006), people are often unable to quickly identify the onset of heat stroke or heat exhaustion symptoms before serious illness ensues (Harlan et al. 2014; Mishra and Suar 2007). As a result, extreme heat is often considered a ''silent killer'' (Klinenberg 2015; Mishra and Suar 2007; Poumadère et al. 2005). Research on thermal comfort can provide techniques to mitigate heat exposure to avoid unnecessary loss of life and enhance urban planning (Chen and Ng 2012). Experts are investigating ways to measure heat stress in humans more accurately (Kuras et al. 2017; Lee et al. 2013, 2016) but such methods are not yet being used in the hazards and risk communication fields.

This study explores the influence of subjective experiences with heat-health effects in a model that also incorporates traditional predictors of behavior including risk perception and temperature exposure. If previous experience with negative health effects of heat increases one's protective actions, heat risk prevention plans and campaigns may be able to use the unique aspects of experience to communicate heat risk more effectively, mobilize adaptive practices, and ultimately improve current extreme heat event guidance (CDC 2018). Designing messages that elicit memories of past events, for example, or that help people connect with the visceral health experiences of others, may increase the effectiveness of messages, warnings, and advisories.

d. *Differentiating protective behaviors*

Protective behaviors can be viewed or categorized in a variety of ways whether egocentric, prosocial, or purely altruistic (Piliavin and Charng 1990; Haski-Leventhal 2009; Piliavin 2001). In disaster situations, the stress caused by the event promotes many people to act on behalf of others' welfare and enhance social cohesion in their communities while at the same time other people express antisocial behaviors more frequently (e.g., crime; Lemieux 2014). Furthermore, people are more willing to express concern and act on behalf of others when they know the person and when they think no else will help (Lemieux 2014). This literature suggests that responses to extreme heat may manifest differently according to the altruistic nature of different populations. Populations may also respond differently for heat hazards because of their ''silent'' nature. For example, if people believe the threats of extreme heat will manifest before officials respond, will they act on others' behalf more readily? Our study examines four behaviors that are focused on preserving personal health during a heat wave and one behavior that focuses on preserving the well-being of others.

e. *Spatial variation*

While previous research establishes who may be more physiologically and socioeconomically vulnerable to extreme heat, little research explains how spatial factors contribute to people's decisions to adapt to the hazard. Although localized studies have measured protective behaviors through surveys, interviews, or experiments (Akompab et al. 2013; Alberini et al. 2011; Kalkstein and Sheridan 2007; Khare et al. 2015; Kim et al. 2014; Lefevre et al. 2015; Romero-Lankao et al. 2014; Sheridan 2007; White-Newsome et al. 2011), we are not aware of a study that has assessed what influences adaptive or protective behaviors on a national level for the United States.

It is important to understand spatial variation in heat response behaviors in order to provide context for creating population and location-specific preparedness initiatives. Heat exposure varies widely across the United States, and urban heat islands also create localized extremes that exacerbate heat exposure in densely populated areas, especially in areas with little vegetation cover (Clarke 1972; Harlan et al. 2006). This varied exposure creates different levels of acclimatization among populations according to local norms and makes experiences of extreme heat a subjective threshold that may be partially explained geographically. Protective behaviors in response to these thresholds may also be spatially dependent. Understanding the factors that influence protective behaviors at different geographic scales will help practitioners create effective heat wave response programs both locally and regionally (Browning et al. 2006; Klinenberg 2015; Lee et al. 2015).

3. Methods

We used survey and temperature data from 2015 to investigate the aforementioned questions (Esplin et al. 2018);

2015 was the second warmest year on record for the contiguous United States (NOAA 2015), and every state had an annual temperature warmer than the twentieth-century average (1901–2000) including four states experiencing their warmest year on record. June 2015 was the second warmest June recorded, particularly for the West and Southeast where several western cities set new all-time June temperature records. The South, Northwest, and Northeast were warmer than average in July and several locations in the Northwest and Northeast recorded record warmth in August.

a. Dependent variables

This study is based on georeferenced data from the Climate Change in the American Mind project, a series of nationally representative surveys conducted regularly by the Yale Program on Climate Change Communication and the George Mason Center for Climate Change Communication. Adults 18 and older were sampled from 30 September to 19 October 2015 online via the GfK Knowledge Panel ($n = 1330$), which uses probabilistic, address-based sampling. The survey had an average margin of error of ±3% at 95% confidence (Leiserowitz et al. 2015). GfK anonymized the locations of participants through a random jittering process within 150 m of their household address.

This survey measured five heat protective behaviors with the following question and a four-point scale for each item (never, rarely, occasionally, often):

> ''When your local area experiences a heat wave, how often do you do the following?''
>
> (Use fans at home; Stay indoors; Use air conditioning at home; Check in on family, friends, or neighbors; Leave home and go to a cooler place)

Responses were dichotomized into two groups: ''never'' and ''rarely'' as one group and ''occasionally'' and ''often'' as the other. Between 153 and 156 participants who declined to respond to any of these five items were excluded from the model. An alternative dichotomization was also analyzed by grouping ''never'' responses alone, and ''rarely'' responses with the other response options (see supplemental materials for alternative results).

b. Predictor variables

1) HEALTH EXPERIENCE AND RISK PERCEPTION

The survey measured the negative effects of heat-related health symptoms with the following items:

> ''How often have you experienced the following effects of heat waves during the past year?''
>
> [Decreased productivity at work; Personal discomfort; Heat-related illness (such as heat exhaustion or heat stroke)]

Each item was measured with a four-point scale (never, rarely, occasionally, and often). Cronbach's α indicated that the sum of these three items into a scale was reliable ($\alpha = 0.746$) (DeVellis 2016). The values for these three questions were summed and divided by the maximum outcome to create a negative health effects score, which was used as a fixed effect in the model.

Heat wave risk perception was measured in the survey using a slider bar from 0 to 100 with the following items:

> ''A heat wave is a period of unusually and uncomfortably hot weather. If a heat wave were to occur in your local area, how much, if at all, do you think it would harm the following?''
>
> (Your health; The health of others in your community)

The slider bar included a descriptive scale (Would cause no harm at all; A little harm; Moderate harm; A great deal of harm; Would cause extreme harm). Cronbach's α indicated a combination of these two items into a scale was reliable ($\alpha = 0.902$) (DeVellis 2016). The values for these two questions were summed and divided by the maximum outcome to create a risk perception score used as a fixed effect in the model.

2) SOCIODEMOGRAPHIC CHARACTERISTICS AND SPATIAL SCALES

Demographic characteristics collected from the survey were used as random effects according to the conceptual model in Fig. 1. Income levels were binned to reflect fairly equal numbers of respondents at each level. To control for behaviors that may be related to having access to air conditioning, a variable indicating access to air conditioning (''AnyAC'') was included as a random effect by dichotomizing between those who reported having central air or a window AC unit and those who have neither. Any ''refused'' responses to either type of AC were coded as having no AC access overall ($n = 24$). Self-reported political ideology was consolidated into three groups: liberal, conservative, and moderate, and included as a random effect. Including political ideology in this model tested if the climate beliefs and perceptions of local temperature found to be associated with political orientation also manifest in protective behaviors for this hazard (Howe and Leiserowitz 2013; Howe et al. 2013; McCright et al. 2014). Random effects for county, state,

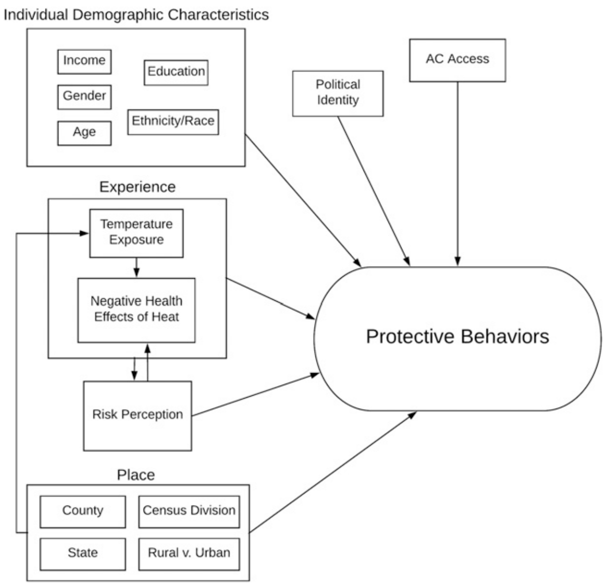

FIG. 1. Conceptual model used to build a multilevel logistic regression model to investigate heat protective behaviors in the United States. Arrows indicate direction of possible influence or association. Note that both experience variables affect risk perception, but risk perception only influences the negative health effects of heat.

and census division were also included. To account for possible variation between urban and rural residents, the 2013 Rural–Urban Continuum Codes from the U.S. Department of Agriculture (USDA) at the county level were used to create another predictor variable. This coding scheme differentiates urban counties by the population size of their metro area and rural counties by the degree of urbanization and adjacency to a metro area. The nine metro codes were dichotomized into two groups: ''metro'' and ''non-metro,'' consistent with the USDA classification scheme.

3) Climatic indicators of exposure

Climatic and temperature exposure were not measured directly in these survey data; therefore, exposure variables based on the locations of survey respondents were created from existing climate data sources. Most heat waves occur from May to September in the Northern Hemisphere and this time frame is often called the warm season (Smith et al. 2013). Monthly mean temperature data for May–September 2015, and 30-yr averages for these months were downloaded at 800-m spatial resolution from the PRISM Climate Group (Oregon State University 2017) and then extracted to the county level. Mean temperature data are appropriate for this context because mean temperatures are highly correlated with maximum and minimum temperatures and extreme heat events are created in part by high daytime temperatures combined with high nightly lows (Smith et al. 2013). The mean values of mean daily temperature for each county's warm season were calculated for the five months of the 2015 warm season and the 30-yr average for the same 5-month period. The 2015 averages were then subtracted from the 30-yr averages to create temperature anomaly values for the warm season immediately prior to survey administration. These two values, the 30-yr average of mean temperature for the 2015 warm season and the 2015 mean temperature anomaly for the warm season, were used as separate climate-related exposure variables at the county level. Using both variables captured relative differences in baseline climatology and seasonal deviations from normal temperature for each location. The county-level 2015 temperature anomaly and 30-yr warm-season average for each respondent were added to the model as the ''exposure'' predictor variables and used as fixed effects alongside the negative health effects and risk perception scores. We also investigated alternative heat wave exposure variables derived from the Daymet dataset (Thornton et al. 2018). These variables represented the number of days the mean temperature exceeded the 90th, 95th, or 99th percentile (based on the 30-yr climatology) for two consecutive days by census tract and averaged per county. These variables are based on previous definitions of heat waves (Anderson and Bell 2011, 2009; Smith et al. 2013). Further explanation of these alternative exposure variables and results are explained in the supplemental materials.

c. *Analytical approach*

The five protective behaviors above were analyzed separately as dependent variables through a multilevel logistic regression model in R using the lme4 (Bates et al. 2015), arm (Gelman and Su 2016), and sjPlot packages (Lüdecke 2017). Models were built iteratively by adding one random effect at a time. An ANOVA was conducted after each addition and only predictors that improved model fit ($\alpha = 0.10$) were retained. Interactions between significant demographic variables were tested and included or excluded in the same way. This process was conducted for each dependent variable; hence, the demographic random effects differ for each protective behavior model. Random effects that measured spatial variation (region, state, county, and metro versus non-metro) were kept in all models. Fixed effects were added to the model after the random effects. To control for measured exposure, the fixed effects of warm-season 30-yr average temperature and 2015 warm-season temperature

Table 1. Descriptive statistics of variables used as fixed effects in the study. Participants chose between never, rarely, occasionally, and often for each negative health effect item included in the negative health effects score. Participants used a slider bar between 0 and 100 with a descriptive scale (Would cause no harm at all; A little harm; Moderate harm; A great deal of harm; Would cause extreme harm) to respond to the risk perception score items. The values for the score items were summed and divided by the maximum outcome to create a negative health effects score and risk perception score each ranging from 0 to 1. PRISM climate data are reported for May–September (Oregon State University 2017).

Statistic	N	Mean	Std dev
Negative health effects score	1180	0.53	0.19
Risk perception score	1180	0.39	0.24
Warm-season 30-yr average (1985–2015)	1180	21.58°C	3.53°C
2015 warm-season anomaly	1180	0.66°C	0.47°C

anomaly at the county level were kept in the model regardless of effect size and improvement of model fit.

4. Results

On a 0–1 scale, the negative health effects score had a mean of 0.53 (standard deviation $\sigma = 0.19$) and risk perception score had a mean of 0.39 ($\sigma = 0.24$) (Table 1). Most participants reported using air conditioning at home often and never going to a cooler place during a heat wave (Table 2). Responses for checking on family, friends, and neighbors are spread somewhat evenly across all response options. Respondents are representatively distributed across the nine census divisions (region), political ideology, gender, and several levels of age and income (Table 3). The distribution of respondents across the metro versus non-metro counties, race/ethnicity groups, and presence or absence of air conditioning categories was more uneven. Most attributes are representative of the spatial and demographic distribution of the U.S. population. As compared to the 2015 census American Community Survey, ''white, non-Hispanic'' individuals, adults with a bachelor's degree or higher, 45–59-year-olds, and adults 60 years and older are overrepresented in the sample by 8.5%, 7.0%, 8.7%, and 14.5%, respectively. ''Other, non-Hispanic'' individuals and households with less than $25,000 annual income are underrepresented by 7.0% and 6.6%, respectively.

Results from the multilevel logistic regression predicting behavioral responses to extreme heat show that the temperature variables (long-term warm-season mean and 2015 warm-season anomaly) had a small and nonsignificant effect across all protective behaviors while experience with heat-health symptoms had a large positive association with all behaviors (Table 4). Alternative models using percentile thresholds for extreme heat had similar results (See supplemental materials). The effect of risk perception varied depending on the behavior measured. Risk perception and negative health effects had low intercorrelation for all models (between $r = 0.336$ and $r = 0.399$). When considering their associated confidence intervals, negative health effects was a more consistent predictor than risk perception for all behaviors (Fig. 2). Overall, experience with heat-health symptoms was a much stronger predictor than risk perception for all protective behaviors except ''Checking on Others'' and ''Using AC at home,'' where the effect sizes of risk perception were comparably large.

Spatial variables had little influence in most models. Controlling for other variables in the model, households in the South Atlantic census division used AC at home 6 percentage points more than the national average and California households 8 percentage points less than the national average. Californians were 15 percentage points less likely than the national average to check on others. People in the Pacific census division were 16 percentage points more likely to go to a cooler place than people in the South Atlantic and 14 percentage points more likely than the national average. Nonmetro residents were 10 percentage points less likely to stay indoors than metro residents. However, most spatial random effects were not significantly different from the national average.

Risk perception and negative health effects were strong predictors of checking on family, friends, and neighbors during a heat wave (Fig. 3). By contrast, the

Table 2. Descriptive statistics of the protective behaviors analyzed in this study. We show N for each response option with the corresponding percentage of participants who responded to that question in parentheses. We acknowledge that the limitations to the benefits of fan use under certain conditions may influence the results for this particular behavior. N/A indicates not available.

	Never	Rarely	Occasionally	Often	N/A	N
Use fans	103 (8.73%)	110 (9.32%)	288 (24.41%)	675 (57.20%)	4 (0.34%)	1180
Stay indoors	36 (3.05%)	125 (10.59%)	373 (31.61%)	643 (54.49%)	3 (0.25%)	1180
Use AC at home	85 (7.20%)	48 (4.07%)	172 (14.58%)	871 (73.81%)	4 (0.34%)	1180
Check on family, friends, and neighbors	251 (21.27%)	311 (26.36%)	415 (35.17%)	197 (16.69%)	6 (0.51%)	1180
Go to a cooler place	588 (49.83%)	300 (25.42%)	202 (17.12%)	86 (7.29%)	4 (0.34%)	1180

TABLE 3. Descriptive statistics for the individual levels of the random effects used in the multilevel models.

	N	Frequency (%)
Region		
New England	68	5.76
Middle Atlantic	160	13.56
East North Central	171	14.49
West North Central	97	8.22
South Atlantic	219	18.56
East South Central	65	5.51
West South Central	110	9.32
Mountain	91	7.71
Pacific	199	16.86
Rural vs urban		
Metro	1017	86.19
Non-metro	163	13.81
Age (years)		
18–29	174	14.75
30–44	248	21.02
45–59	340	28.81
60+	418	35.42
Any AC at home		
No AC	118	10.00
Yes AC	1062	90
Education		
Less than high school	93	7.88
High school	322	27.29
Some college	352	29.83
Bachelor's degree or higher	413	35.00
Ethnicity/race		
White, non-Hispanic	860	72.88
Black, non-Hispanic	110	9.32
Other, non-Hispanic	45	3.81
Hispanic	130	11.02
Two or more races, non-Hispanic	35	2.97
Gender		
Male	541	45.85
Female	639	54.15
Income		
< $25,000	183	15.51
$25,000–39,999	172	14.58
$40,000–59,999	199	16.86
$60,000–84,999	203	17.20
$85,000–124,999	239	20.25
≥$125,000	184	15.59
Political ideology		
Refused	15	1.27
Liberal	313	26.53
Moderate	471	39.92
Conservative	381	32.29
Total observations	1180	

physical exposure variables (long-term warm-season average temperature and 2015 temperature anomaly) had a negligible influence. The marginal effects of these predictors indicate that 80% of adults with the highest risk perception score would be predicted to report checking on others during a heat wave (Fig. 4). By contrast, adults with the lowest risk perception score have a 33% probability of reporting that they would check on others. Holding risk perception constant, the likelihood that adults with the most prior experience with heat-related health symptoms will check on others is 71% while the likelihood for those with the least experience is 35%.

Demographic random effects exhibited the most variation in predicting checking on others during a heat wave (Table 5). Age was the strongest individual predictor while education had essentially no influence. Adults 45 years and older were 19 (60+ years old) to 20 (45–59-year-olds) percentage points more likely to check on family, friends, and neighbors than younger adults (18–29-year-olds). Other significant predictors include being female (11 percentage points more than males), being black (11 percentage points more than whites and 12 percentage points more than Hispanics), having a moderate political ideology (7 percentage points more than the national average), and having income less than $25,000 (5 percentage points more than the average). Even though education did not significantly predict this behavior, an interaction between education, gender, and political ideology had considerable influence on checking on others, with greater variance ($\sigma^2 = 0.14$) than all other demographic variables except age. Overall, female moderates with less than a high school education were 24 percentage points more likely than the average American to check on others with the highest probability of all random effects in the study [$P = 0.77$, $\beta = 0.57$, standard error (se) = 0.30]. Male conservatives with a high school diploma were 10 percentage points more likely than the national average ($\beta = 0.55$, se = 0.26), and male moderates with some college education were 8 percentage points more likely than the average ($\beta = 0.39$, se = 0.25). Odds ratios for random effects of this model are found in the supplemental materials. Models that alternately dichotomized behavioral responses as ''never'' versus all other responses showed similar results for the main hypothesized predictors, with somewhat smaller demographic effects across all behaviors (see supplemental materials).

5. Discussion

Heat experience can be quantified and inferred by measuring the ambient temperatures to which people are exposed (Kuras et al. 2015, 2017; Hondula et al. 2013; Reid et al. 2012; Tan et al. 2010). However, this method may not fully capture the role of subjective

TABLE 4. Coefficients for fixed effects and number of levels for random effects used in each model. The random effect N_{STATE} includes the District of Columbia and excludes Alaska and Hawaii. Dashes indicate random effects that were not included in the model because their inclusion did not improve model fit with 90% confidence during model iteration. Temperature exposure had little influence on reports of protective behavior while the negative effects of heat on one's health had large effects across all behaviors. Note that few variables fit the model for fan use. This may be due to the beneficial limits of the behavior—using fans above 90°F (32°C) can worsen conditions (EPA 2006). Asterisks indicate significance levels: * is for $p < 0.05$, ** is for $p < 0.01$, and *** is for $p < 0.001$.

	Checking on others		Go to cooler place		Stay indoors		AC use at home		Fan use	
	β	se	β	se	β	se	β	se	β	se
Fixed Parts										
Intercept	−1.99**	0.76	−2.21**	0.82	−0.77	0.86	−1.19	1.72	0.10	0.61
NegHealthEffects_Score	1.64***	0.40	2.71***	0.43	3.12***	0.60	1.78*	0.70	2.17***	0.49
RiskPerception_Score	2.11***	0.32	0.81*	0.34	0.40	0.42	1.21*	0.53	0.22	0.36
WarmSeason_30yr_Average	0.02	0.03	−0.03	0.03	0.03	0.03	0.08	0.05	0.01	0.02
WarmSeason_Anomaly	0.15	0.19	−0.16	0.22	−0.22	0.21	−0.01	0.36	0.02	0.18
Random Parts										
N_{COUNTY}	565		566		566		565		566	
N_{STATE}	49		49		49		49		49	
$N_{EDU: GENDER: POL\_IDEOLOGY}$	30		—		—		—		—	
N_{REGION}	9		9		9		9		9	
N_{INCOME}	6		6		—		6		6	
$N_{RACE/ETHINICITY}$	5		5		—		—		—	
$N_{POLITICAL\_IDEOLOGY}$	4		—		—		—		—	
$N_{EDUCATION}$	4		—		—		4		—	
N_{AGE}	4		4		4		—		—	
$N_{RURALvURBAN}$	2		2		2		2		2	
N_{GENDER}	2		—		2		—		—	
N_{AnyAC}	—		—		2		2		—	
Total observations	1174		1176		1177		1176		1176	

heat-health impacts or their influence on individual protective behaviors. Measurements of subjective experience with extreme heat that include personal health-related impacts have a strong positive relationship with self-reported protective behavior. On average, people in the United States reported taking more protective actions against extreme heat when they had had experience with the negative health effects of heat, such as feelings of discomfort or heat exhaustion. This result could relate to observed decreasing trends in U.S. heat mortality rates (Hondula et al. 2015; Gasparrini et al. 2015; Bobb et al. 2014) as people experience and adapt to heat over time. Assuming there is a causal relationship between experience and behavior, incorporating references to prior experience with heat-health symptoms into risk communication strategies may improve awareness of heat risk and adaptation practices. For example, messaging that triggers memories of people's past negative experiences with heat or, for those who have not had such experiences, that stimulates connecting vicariously with others' negative health experience could promote adaptive practices and motivate people to make heat protection plans. By thinking first about past experiences and results, people may be more likely to evaluate their resources and needs more accurately for future events. Such imaginative exercises could be a key step in plans to help municipalities be more prepared for future heat waves.

This study indicates that heat risk perception's relationship with adaptive practices varies across behaviors. Risk perception predicted the chances that people would check on others more than prior experience with negative health symptoms, but this relationship did not hold for other protective behaviors. Assuming this is a causal relationship, high perception of heat risk may encourage people to think about others and act altruistically, but not motivate individuals as much to protect themselves personally against heat by using fans, staying indoors, or going to a cooler place. In contrast, prior experience with heat-health symptoms consistently predicted altruistic and personal protective actions. This supports the importance of measuring direct, negative impacts of a hazard (Dillon et al. 2014, 2011; Sharma and Patt 2012). While risk perception is an important indicator of vulnerability (Jonsson and Lundgren 2015; Slovic 1987; Zografos et al. 2016), prior experience with heat-related health symptoms is a related and possibly more consistent predictor of behavior and should be

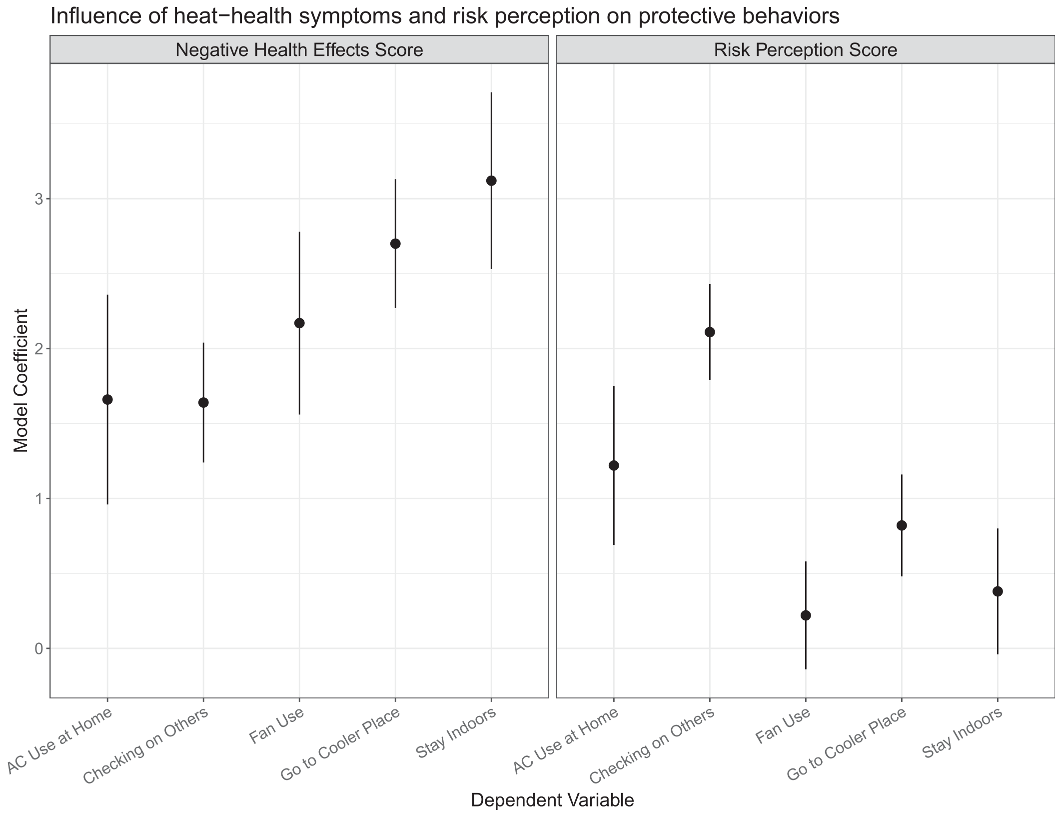

FIG. 2. Coefficients of (left) the negative health effects of heat and (right) risk perception for all measured protective behaviors. Note that although risk perception had more influence on checking on others than negative health effects, negative health effects influenced fan use, going to a cooler place, and staying indoors much more.

considered part of how heat experience is measured in future work.

For future risk communication studies, harnessing the predictive influence of prior heat-health experience on protective behavior into an effective risk communication tool has the potential to reduce vulnerability and increase resilience among populations that may not otherwise have the immediate resources to reduce their risk through other means. For example, creating messaging about the signs of and treatment for heat stroke that triggers memory of negative experiences with heat-health symptoms may help people take precautionary steps to protect themselves and those around them. This work calls for exploration of heat-health experience as a risk communication tool.

The personal protective behaviors measured in this study were not heavily influenced by sociodemographic characteristics, a result that contrasts with other research regarding heat risk (Wilhelmi and Hayden 2010). Although indicators like age, gender, race or ethnicity, income, and education are good predictors for risk perception and vulnerability, reported heat protective behaviors span these groups regardless of their risk. Many of these behaviors are accessible to most of the population across different demographic characteristics, which supports the notion that heat morbidity and mortality are preventable when people have both the right information and access to resources

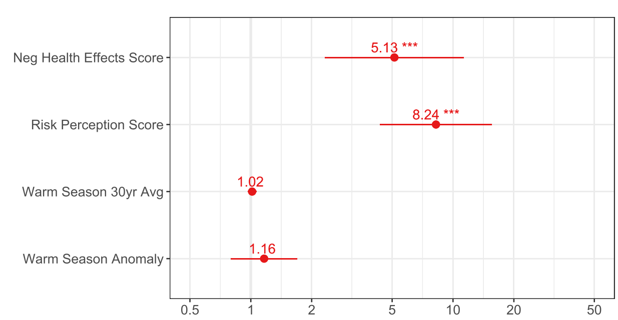

FIG. 3. Odds ratios for the fixed effects of checking on others during a heat wave. People with the highest risk perception reported checking on others during a heat wave 27% more than the average American. People with the most prior experience with heat-health symptoms reported checking on others 18% more than the average American. Both warm-season effects are not significantly different than the average.

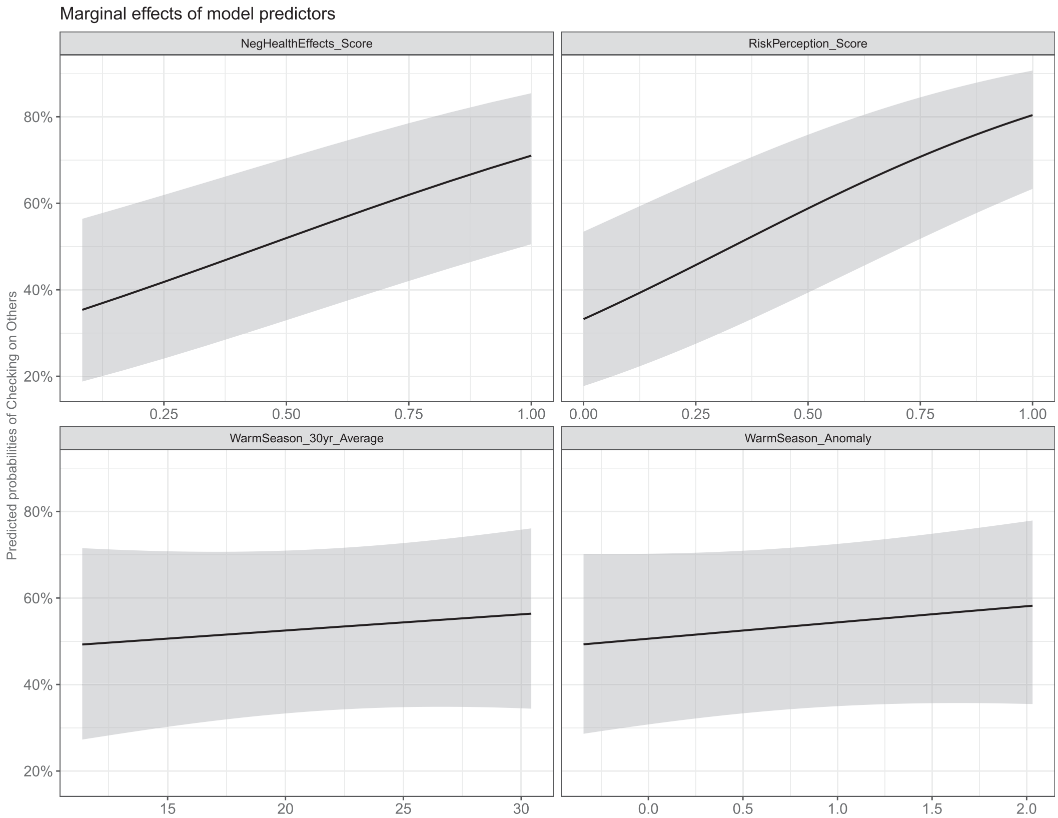

FIG. 4. The marginal effects of checking on others during a heat wave. Adults who reported the most prior experience with heat-health symptoms reported checking on friends, family, and neighbors 36% more than adults who had the least experience with these symptoms. Adults who reported the highest risk perception reported checking on others 47% more than adults who did not perceive this risk.

at the right time. Although there are financial constraints to accessing air conditioning, other effective behaviors examined here are generally accessible and low cost.

Even so, in the model for going to a cooler place, income is not the only constraining variable for this behavior; age and ethnicity also play a role. This is not surprising because age can impede mobility and low-income households may not be able to afford transportation to a cooler place or feel safe going out in their neighborhoods (Klinenberg 2015). Overall, it appears that when people had access to AC and the income to afford this amenity, they used it instead of going to a cooler place regardless of cultural boundaries, but when people did not have air conditioning or could not afford its use, some demographic influences differentiated who seeks out a cooler location and who does not. Staying indoors is another protective behavior that is accessible to the majority of the population, with the exception of those who work outside or are required to engage in other activities outside. In this study, older adults and men tended to stay indoors less during a heat wave than younger adults and women. This model supports previous research stating that men have lower heat risk perceptions (Kalkstein and Sheridan 2007; Klinenberg 2015) and that older adults may not consider themselves to be part of a vulnerable population; they may not see themselves to be at risk in part because they may not consider themselves to be elderly (Wolf et al. 2010a).

This research contributes to the heat risk research literature by distinguishing what predicts specific self-reported protective behaviors. In particular, we identified a unique difference between altruistic and personal behaviors. Checking on others was the only altruistic protective behavior measured and although this is something most adults can do, this behavior was influenced more heavily by sociodemographic factors than any other. Adults 45 years and older tended to check on family, friends, and neighbors more than 18–29-year-old adults. The opposite effect applies to the relationships between age and personal protective behaviors, with 18–29-year-olds tending to personally protect themselves and older adults (45 and older) less so. This is consistent with studies that found

TABLE 5. Results for "Checking on Others" model. Risk perception and prior experience with heat-health symptoms greatly increased the likelihood that Americans will check on their family, friends, and neighbors. Note that there is no spatial variation detected by the county or the rural vs urban spatial levels or by education for this behavior. Asterisks indicate significance levels: * is for $p < 0.05$, ** is for $p < 0.01$, and *** is for $p < 0.001$.

	β	se
Fixed Parts		
Intercept	−1.99**	0.76
NegHealthEffects_Score	1.64***	0.40
RiskPerception_Score	2.11***	0.32
WarmSeason_30yr_Average	0.02	0.03
WarmSeason_Anomaly	0.15	0.19
Random Parts		
$\tau_{00,\text{COUNTY}}$	0.000	
$\tau_{00,\text{STATE}}$	0.088	
$\tau_{00,\text{EDU: GENDER: POL\_IDEOLOGY}}$	0.140	
$\tau_{00,\text{REGION}}$	0.017	
$\tau_{00,\text{INCOME}}$	0.032	
$\tau_{00,\text{RACE/ETHNICITY}}$	0.081	
$\tau_{00,\text{POLITICAL\_IDEOLOGY}}$	0.086	
$\tau_{00,\text{EDUCATION}}$	0.000	
$\tau_{00,\text{AGE}}$	0.151	
$\tau_{00,\text{RURALvURBAN}}$	0.000	
$\tau_{00,\text{GENDER}}$	0.096	
Total observations	1174	

older adults manifest more prosocial behaviors (Haski-Leventhal 2009) and implies that older adults may be more concerned about others' than their own health, while younger adults act to protect themselves from the heat but are less likely to transfer this concern to helping those around them. This knowledge can help practitioners emphasize certain aspects of heat risk messaging and planning for different groups. Interactions with older adults can emphasize the need to take care of one's health so they are able to help others effectively, and outreach with younger adults can encourage them to be more aware of vulnerable people around them and what they can do to help.

Other demographic predictors including gender and race/ethnicity had some association with altruistic self-reported behaviors. On average, men tend to check on others during a heat wave less than women, and black or African American respondents tended to check on others more than white respondents. Previous research has found that men perceive lower risk from heat (Kalkstein and Sheridan 2007; Klinenberg 2015; Harlan et al. 2014), which may lead them to be less aware of the threat to others and therefore act less altruistically. Community heat protection plans may maximize their efforts by both incorporating women more directly into their strategies to check on neighbors and encouraging men to be more active in checking on others and to be aware of their own risk. African Americans and older adults could also be recruited for neighborhood outreach initiatives. Contrary to previous studies regarding the resilience of Hispanic communities to extreme heat events (Kalkstein and Sheridan 2007; Klinenberg 2015), this study found that Hispanic respondents did not check on others more than white respondents. Although the observed cohesive nature of Hispanic communities may be present in many locations, more research on the adaptive capacity of these communities is needed, as Hispanics are one of the ethnic groups most exposed to heat based on their geographic distribution in the United States. These results may also indicate the importance of group influence and collective norms in determining altruistic actions (Haski-Leventhal 2009).

Although education significantly improved the model fit for checking on others, its influence was negligible altogether. A person's education level may not necessarily be indicative of their knowledge of what causes heat vulnerability and how to avoid and treat it, or their ability to implement this knowledge. Regardless of understanding these principles, several other factors influence or impede one's ability to implement protective action and these barriers must be overcome in order to foster preparedness and response (Jenerette et al. 2011; Harlan et al. 2006; White-Newsome et al. 2014).

Only one interaction term predicted the altruistic behavior of checking on others. Although education had negligible influence on its own, relationships emerge when education was coupled with political ideology and gender, both with moderate to large effect sizes. For most groups, as education increased, the likelihood of checking on others decreased. The only groups that responded differently were female moderates with less than a high school diploma, male conservatives with a high school diploma, and male moderates with some college education. Such interactions may explain the specific groups responsible for the marginal effect of political ideology, and add an additional dimension to the finding that men check on others less than women in general. Clearly this interaction is complex, but indicates that these exceptions to the individual predictors are large associations that should be investigated and possibly considered when drawing conclusions about altruistic behaviors for certain groups. This finding calls for further inquiry to understand what implications the combination of these influences may have for risk communication and emergency management officials seeking to maximize strategies and efforts to build heat resilient communities.

Although the spatial variables did not predict protective behaviors, including them did help control for possible biases introduced by spatial clustering. The absence of significant spatial effects may explain the subjectivity of heat experience. Although experience with heat-health symptoms improved the ability to measure heat behavior, these symptoms manifest on an individual level and may be dependent on other factors not measured in the study. Chronic health conditions and health status influence when heat-related health symptoms occur (Anderson and Bell 2009, 2011; Sampson et al. 2013). Different acclimatization levels can alter resilience to heat for people who travel from a cooler climate to a warmer one even though they have good health status and do not have chronic health conditions. Localized acclimatization may explain why there is little spatial variation for these protective behaviors. Extreme heat occurs in all regions of the United States but the threshold of what is considered extreme is dependent on climate and different personal thresholds of heat tolerance. People feel the effects of "extreme" heat differently and depending on the climate they are accustomed to.

To summarize, although the altruistic action of checking on family, friends, and neighbors can be performed by most people with little or no monetary cost like some of the other behaviors analyzed in this study, societal and cultural norms may influence whether Americans choose to do so. It is possible there are social barriers that impede or encourage people to reach out to others at risk to heat stress. These barriers can depend on neighborhood culture or social norms of any given cultural or generational group as well as broad expectations of American society in general (Klinenberg 2015; Colten and Sumpter 2009; Poumadère et al. 2005; Wolf et al. 2010b; Lemieux 2014). As noted by Klinenberg (2015), the "silent" nature of heat waves can delay official government response; potentially vulnerable neighborhoods may go unnoticed for some time. It is possible these more altruistic groups act on behalf of others more readily during heat events because they are from neighborhoods where they think no one else will respond in time (Lemieux 2014). Further research on this particular behavior as well as other altruistic behaviors in the context of heat may better inform the nature of altruistic actions that are unique to this specific hazard and what that means for practitioners striving to better mitigate heat risk in their communities.

6. Limitations

This study has several limitations, including the possible bias introduced by the nature of self-reported survey data. Participants may have reported inaccurate measures of their experience with heat-health symptoms, heat risk perceptions, and protective behaviors because of poor memory recall or desire to appear more or less experienced with symptoms, aware of the risk, or active in protecting themselves or others. Coupling survey results with an experimental design that measures the actual occurrence of heat-health symptoms and protective actions would be a useful next step in future research. The spatial and temporal scale used in this analysis may be too coarse to see high-resolution variation of participant exposure to heat, such as within counties. Although the climatological variables used to measure exposure were georeferenced to each respondent's county, there may be short-term weather and finescale effects within the summer season on reported behavior that may not be captured by the temperature variables used here. The scale limitation is also related to the survey sample; since the survey was nationally representative, more people were sampled from densely populated areas than from low-density areas. The possible influence of air conditioning on the measured behaviors would also be better understood with more information about which participants cannot afford its use and those who do not have access to AC (who represented only 10% of our sample). Last, only five heat-protective behaviors and three heat-health effects were analyzed. Additional important behaviors and health effects could be examined in future work.

7. Conclusions

Life and property are threatened when human behaviors are insufficient to protect against extreme heat. The heat risk research community acknowledges heat-health symptoms as a major impact of extreme heat events (Kuras et al. 2017, 2015), yet few studies use this direct effect to enhance heat experience measurements attempting to predict behavior and preparedness (Mishra and Suar 2007). This study addresses this gap by examining subjective experience with the negative effects of heat on one's health. We found that experience with heat-health symptoms strongly influenced self-reported protective behaviors while traditional measures of heat exposure had little influence. This finding supports the heat risk research community's call to measure exposure on an individual level (Kuras et al. 2017). Risk perceptions had an important but smaller influence on behaviors than did previous experience. At least 60% of participants had previously experienced some heat-related health symptoms. As time passes, it is likely that more people will accumulate this experience as heat wave frequency increases. Therefore, this experience should be incorporated regularly into heat experience measurements alongside temperature exposure in order to provide more accurate insight on what motivates people to protect themselves during extreme heat. Risk communication and risk planning professionals can use these findings to better promote heat protective behaviors for different U.S. populations, improve local heat protection plans, and thereby more effectively prevent unnecessary suffering and loss of life due to heat exposure.

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