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RESEARCH ARTICLE

Extreme heat & public perception in Portland, Oregon: Evidence of a compounding vulnerability effect for climate hazards

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Abstract

Extreme heat events are a global public health threat, and the frequency of these events are projected to increase significantly in the coming decades. Responding to extreme heat requires that municipalities communicate with public audiences. Generally speaking, risk communication and public engagement efforts are more effective when they are responsive to current risk perception trends. This social scientific study examines extreme heat risk perceptions, emergency response needs, and level of trust in first responders among residents of the Portland (OR) Metro Area. Using quantitative survey data, it demonstrates the compounding influence of three previously identified vulnerability indicators–poverty, disability, and race–on public perception surrounding extreme heat and environmental emergencies. Results show these vulnerability indicators have a significant compounding effect on public perception, such that an increased number of vulnerability indicators is associated with greater anticipated harm from extreme heat, higher anticipated need in the event of an environmental emergency, and lower trust in first responders. Firefighters and medical providers were the most trusted first responders across all vulnerability groups. Guidelines for public engagement and recommendations for future social scientific research are discussed.

Introduction

Extreme heat is a global public health threat [1] and the most lethal weather-related risk in the United States [2]. The impacts of extreme heat are well documented, and include infrastructure damage [3], power grid interruptions [4], heat-related illnesses [5], increased emergency room visits [6], and increased morbidity [7]. The percentage of the world's population living in areas where temperatures reach a fatal threshold is expected to increase to almost 50% in the next 80 years [8]. Even if the most ambitious carbon reduction measures are implemented, extreme heat events will pose an increasing risk to even the healthiest of individuals [9,10]. Given this enduring and increasing threat, many municipalities are taking steps to better prepare for and respond to such events [11].

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Responding to extreme heat requires that municipalities engage public audiences. Public engagement strategies for extreme heat might include, for example, information dissemination campaigns or the mobilization of first responders to monitor and check in on the most vulnerable [12]. Importantly, risk communication and public engagement efforts are more effective when they are responsive to current public risk perceptions [13,14]. To effectively and equitably protect the public, it is particularly crucial that special attention is paid to the perceptions and experiences of vulnerable populations. In this study, we examine the opinions and perspectives of people living in the Portland Metro Area (PMA). Specifically, we explore whether the number of vulnerabilities a person experiences influences their extreme heat risk perceptions, emergency response needs, and level of trust in first responders. Results demonstrate the compounding influence of three previously identified heat vulnerability indicators–disability, poverty, and race–on public perception surrounding extreme heat and environmental emergencies.

Vulnerability to extreme heat

The death of 72 people during a record setting heatwave in June 2021 highlights the risk of extreme heat faced by the Portland, Oregon area [15,16]. While most people will experience the effects of extreme heat, vulnerability to extreme heat is inequitably distributed. Vulnerability to extreme heat can be understood as an intersection of three factors: exposure to extreme heat events, sensitivity to those events, and ability to adapt to those events [17]. Those with exposure, sensitivity, and lower adaptive capacity are especially vulnerable to extreme heat. Recent work illustrates that these factors vary among populations in Portland according to individual-level and geospatial-level characteristics [18–20], including age [21], income [22], race [23], disability [24], and the geographic features of surrounding landscapes [18].

This study focuses on three of the most common vulnerability indicators identified as significant in prior work: disability, poverty, and race. These indicators are especially relevant for the Portland Metro Area, as more than 82,000 residents, or 12.9% of Portland's population, identify as having a disability [25], and more than 165,000 residents, or 26.2% of Portland's population, identify as a racial minority [26]. Approximately 13% of Oregon's population live below the federal poverty line [27]. Within the seven counties that comprise the greater Portland Metro area, approximately 9.7% of all households are in poverty [28].

Climate extremes represent a significant and increasing threat to people with disabilities (PWD) [29]. Vulnerability to extreme heat for PWD can vary according to disability type. Some physical disabilities, for example, render individuals unable to regulate their own body temperature [30], making them more susceptible to health effects from temperature extremes. Other physical disabilities may present mobility challenges, decreasing the accessibility of relief when extreme heat events occur [31]. Mental disabilities have also been shown to increase vulnerability to extreme heat, as extreme heat events can exacerbate preexisting mental disorders, leading to increased emergency room visits [32,33] (the cited studies classified mental disorders according to the World Health Organization's International Classification of Disease, Ninth Revision [ICD-9:290–319] and Tenth Revision [ICD-10:F00-F99]). The increased vulnerability to extreme heat for PWD translates into a higher need for care. Evidence suggests that PWD anticipate having greater needs in the event of an environmental emergency [34] and are more likely to seek emergency medical care during a heat wave compared to those without disabilities [24]. Remarkably, recent evidence suggests that the health disparities introduced by exposure to extreme temperatures increases over time for PWD, but decreases over time for those without disabilities [35].

PWD commonly perceive themselves to be at greater risk from heat waves [36], and they may require additional support in preparing for and responding to a natural disaster or

extreme weather event. For example, PWD may require assistance and more time to access a cooling center or to evacuate, and therefore need information in advance, and may also need special accommodations for electrical or battery-powered medical devices, service animals, or medications requiring refrigeration. Some PWD may also need financial support to adequately prepare for and recover from disasters [37]. At the same time, prior research suggests that PWD report more negative experiences with and perceptions of the first responders who would be responsible for aiding them during an extreme heat event, including government representatives [38], police officers [39], and medical providers [40,41].

Like people with disabilities, people experiencing poverty have been shown to be especially vulnerable to environmental risks and climate extremes [42]. Low-income individuals and families are more likely to live in substandard housing that provides less protection against extreme heat events [43] and/or in areas with inadequate green space [44] needed to cool temperatures and provide refuge. They are less likely to have air conditioning in their homes [45] and more likely to suffer from health complications [46] that can exacerbate the effects of extreme heat events. Social scientific research shows that the perceptions and experiences of people experiencing poverty surrounding extreme heat often mirror the reality of their increased vulnerability. For example, low-income individuals in the United States perceive themselves to be at greater risk from heat waves [36] compared to those with higher incomes. These differences are also present at the neighborhood level, such that poorer neighborhoods in the United States typically have higher collective risk perceptions compared to wealthier neighborhoods [47]. Those living in poverty also have higher comparative needs in response to environmental extremes, as they are more likely to need greater financial assistance for things like housing and basic necessities [48]. Additionally, as with PWD, those living in poverty report more negative experiences with and perceptions of the first responders who are responsible for aiding them during an extreme environmental event, like government representatives [49] and medical providers [50].

Many studies show that race also determines vulnerability to extreme heat [23,51–54] as a result of structural racism [55]. Exposure to extreme heat is often higher among racial minorities [56] and prior research suggests that communities of color have reduced access to ameliorating circumstances. For example, black households in US metro areas are less than half as likely to have air conditioning compared to white households [57], and studies consistently show that access to green space is lower among racial minorities [58]. Additionally, pre-existing health disparities among minority populations [59,60] can exacerbate the effects of environmental emergencies like extreme heat. The increased vulnerability of racial minorities to extreme heat has been attributed to a variety of structural factors, including increased poverty rates, language barriers, residential segregation, and a higher likelihood of occupation-related exposure [such as working outside] [56,58]. Risk perceptions for extreme heat in neighborhoods of color in the United States are typically higher than those in white neighborhoods, reflecting their increased vulnerability [47]. Additionally, studies suggest that racial minorities commonly have negative experiences with and perceptions of the first responders providing aid during an extreme heat event, including government representatives [61], police [62,63], and healthcare providers [64–66].

Compounding vulnerabilities

Prior research shows that disability, poverty, and race are each associated with increased vulnerability to extreme heat in the United States. Understanding the subjective experiences of vulnerable populations is a vital component of ensuring resilience in the face of climate extremes [67]. To that end, prior work has examined the perspectives and experiences of PWD

[34], those living in poverty [42], and racial minorities [57] within the context of climate threats. However, that prior work has largely examined vulnerable groups in isolation, examining PWD *or* those living in poverty *or* racial minorities. Research exploring the influence of compounding vulnerability indicators on public perception is lacking. Similar to the concept of compounding climate hazards [68], individuals and communities commonly face compounding vulnerabilities to those hazards. For example, PWD are more likely to face other social disadvantages that multiply their susceptibility to climate risks, like being a racial or ethnic minority, being elderly, or being unemployed [69,70]. Similarly, poverty rates are typically higher among communities of color and the disabled [27].

Because climate impacts rarely occur in isolation, we explore the potential influence of compounding vulnerability on the subjective experiences and perceptions of those populations that are most at risk. These differences may be important to attend to as public engagement efforts increasingly attempt to engage vulnerable groups in disaster planning [71,72]. At the time of writing, very few, if any, studies have examined the potential influence of compounding vulnerability on public risk perceptions regarding extreme heat. By filling the critical knowledge gap of how public risk perception is influenced by compounding vulnerability, our study will strengthen disaster planning efforts that directly engage those that face the greatest dangers from climate change.

Hypotheses

Prior research has shown that PWD, those living in poverty, and racial minorities are more likely to suffer from extreme heat and struggle to obtain the resources they need to respond to that heat, while being less likely to trust the first responders who provide assistance. We anticipate that overlapping vulnerability indicators will exacerbate risk perception in these three areas. Specifically, we hypothesize:

H1: The more vulnerability indicators a person has, the more they will anticipate being harmed by extreme heat.

H2: The more vulnerability indicators a person has, the more comparative needs they will anticipate in the event of an environmental emergency like extreme heat.

H3: The more vulnerability indicators a person has, the less trust they will have in first responders to take care of people like them in the event of an environmental emergency like extreme heat, including (a) government, (b) firefighters, (c) medical providers, and (d) police.

Materials & methods

Study procedures and measures were reviewed and approved by the Portland State University Human Research Protection Program prior to data collection (approval #227819–18). Upon approval, people living in the Portland Metro Area were invited to participate in an online survey. Participant recruitment began on August 31, 2022 and ended September 20, 2022. Informed consent was provided electronically at the beginning of the survey. Formal consent was obtained digitally. Data collection and participant compensation were managed by Survey USA. The recruitment strategy included an over-sample of people living in zip codes known to be at higher risk for environmental hazards, including those living near major highways, in neighborhoods bordering the airport, and downtown.

The results presented here are part of a larger survey effort focused on risk perceptions of environmental extremes in the Portland Metro Area. Participants were asked questions about

their perception of wildfire smoke and extreme heat, including how likely they felt they were to be harmed by such extremes. In addition to the variables utilized in the current study, participants were also asked general questions about their environmental emergency preparedness, preferences for government response to environmental hazards, and where and from whom they sought environmental hazards information. Verbatim survey questions used in the current analyses are included in the description of our measures. A copy of the entire survey protocol is available in supplemental materials.

Statistical analyses

Data were statistically analyzed using the IBM Statistical Package for the Social Sciences (SPSS), Version 29. The alpha level threshold for significance for all tests was set a priori at ≤ 0.05. We began our analyses by assessing the reliability of our measures. To do so, we used Cronbach's alpha [73] and report those results in our description of measures. To test our hypotheses, we used one-way analysis of variance (ANOVA). One way ANOVAs allow for the comparison of mean scores between more than two groups, utilizing a nominal grouping variable (vulnerability count, in our case) and continuous outcome variables (anticipated harm, comparative need, and trust in first responders, in our case) [74]. One-way ANOVAs can detect the main effect of the grouping variable on an outcome variable, but it does not allow for pair-wise comparison. As such, a Tukey HSD post hoc analysis was used following each significant one-way ANOVA for pair-wise comparison to identify which of the three groups were significantly different from one another [75]. One-way ANOVAs and Tukey HSD post-hoc analyses are commonly used in the social sciences [76,77] and the field of science communication [78,79].

Participants

The Portland Metro Area spans northwestern Oregon and southwestern Washington state. Participants (n = 1,416) were recruited by Survey USA [80] from six counties in this area, including five counties in Oregon (Multnomah, Clackamas, Washington, Columbia, and Yamhill) and one county in Washington State (Clark). Approximately half of participants (n = 735, 51.9%) identified as women and slightly less than half (n = 645, 45.6%) identified as men (2.5%, or 36 participants, preferred not to say). Most participants identified as white (n = 1077, 76.1%), followed by Hispanic (n = 108, 7.6%), black (n = 78, 5.5%), Asian (n = 71, 5.0%), American Indian or Alaska Native (n = 21, 1.5%), Native Hawaiian or Pacific Islander (n = 14, 1.0%) or 'other' (n = 47, 3.3%). In terms of education, 21.3% (n = 302) completed high school, 37.6% (n = 532) completed some college, 26.1% (n = 370) completed a bachelor's degree, and 15% (n = 212) obtained a postgraduate degree. For a summary of descriptive statistics regarding sample demographics, see Table 1.

We are confident that our sample is high quality and sufficiently reflective of the greater Portland Metro Area for three reasons. First, the population of the Portland Metro Area at the time data were collected (2022) was approximately 2.51 million [81]. Using Cochran's equation for large populations [82] to estimate sample size (assuming a 99% confidence level, 4% confidence interval, and alpha of 0.05) a sample size of 1,037 is needed [83]. Our sample size (n = 1,416) is larger than this recommendation. Second, the demographics the Portland Metro Area are close to that of our sample in terms of gender (50% female and 51.9% female, respectively), race (69% white and 76.1% white, respectively), and education (median education of 'some college') [81]. Third, multiple data quality measures were taken, including 'attention check' questions embedded within the survey, which allowed us to remove respondents who did not seem to be paying attention and those who did not take sufficient time to read the survey questions.

Table 1. Descriptive statistics for sample demographics and vulnerability group characteristics.

Sample Demographics			
	Response Category	**(n)**	**%**
Gender	Female	735	51.9
	Male	645	45.6
	Preferred not to say	36	2.5
Race/Ethnicity	White	1077	76.1
	Hispanic	108	7.6
	Black	78	5.5
	Asian	71	5.0
	American Indian, Alaska Native	21	1.5
	Native Hawaiian, Pacific Islander	14	1.0
	Other	47	3.3
Education	High School	302	21.3
	Some College	532	37.6
	Bachelor's Degree	370	26.1
	Postgraduate Degree	212	15.0
Household Annual Income	Less than $25,000	288	20.3
	$25,000 - $50,000	368	26.0
	$50,000 - $75,000	266	18.8
	$75,000 - $100,000	204	14.4
	More than $100,000	290	20.5
Disability Status	Physical	318	22.5
	Learning	147	10.4
	Neurological	136	9.6
	Psychosocial	131	9.3
	Hearing	127	9.0
	Vision	88	6.2
	Intellectual	70	4.9
	Other	55	3.9

Composition of Vulnerability Indicators across Groups

Vuln. Indic.	**Disability [n]**	**Poverty [n]**	**Racial Minority [n]**
0	0	0	0
1	329	87	172
2+	259	201	167

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Dependent measures

Anticipated harm. Anticipated harm surrounding extreme heat was measured by adapting scales previously used [47]. Participants were asked "If a heat wave happened in your city, how much, if at all, do you think it would harm each of the following?" and given three referent categories: *your health*, *the health of others in your family*, and *the health of others in your community*. Participants responded on a 5-point scale for each category ranging from "None at all" (1) to "A great deal" (5), with an option to select "not sure." Those who responded "not sure" to any of the three items were removed from further analysis. When taken together, these three items had high reliability ($\alpha = 0.838$). As such, they were averaged together into a single 'anticipated harm' index ($M = 3.05$, $SD = 0.99$).

Comparative need. Participants were asked a series of questions to assess their environmental emergency preparedness. These items were developed based on prior qualitative

research that examined the unique needs faced by people with disabilities in the event of environmental disasters [34]. The preamble for this set of questions was as follows: "We want to know more about how prepared you feel you are to respond to an environmental emergency. Environmental emergencies might include things like wildfires, heat waves, severe air pollution, or other extreme weather events." Three of these questions aimed to assess participants' view of their own needs in the event of an environmental emergency compared to other people, including: "I need to get emergency information before other people," (M = 2.93, SD = 1.036); "It takes me longer to respond in the event of an emergency compared to other people," (M = 2.66, SD = 1.215); and "I have a greater need for support during an emergency than other people" (M = 2.65, SD = 1.309). Participants were asked to respond to these items on a 5-point scale from "Strongly Disagree" (1) to "Strongly Agree" (5) with an option to select "not sure." Those who responded "not sure" were removed from further analysis. Reliability for these three items was sufficient ($\alpha = 0.642$), so the items were combined into a single 'comparative need' index (M = 2.75, SD = 0.923).

Trust in first responders. Trust in first responders was measured by adapting previously used survey questions [84]. Participants were asked "How much do you trust or distrust the following groups to take care of people like you during an environmental emergency, like a heat wave or period of heavy wildfire smoke?" Participants were originally given six first-responder referent groups, including: *your city government*, *your county government*, *Oregon state government*, *police*, *medical providers (doctors*, *nurses*, *emergency personnel*, *etc.)*, and *firefighters*. They responded on a 5-point scale from "completely distrust" (1) to "completely trust (5), with an option to select "not sure." Those who responded "not sure" were removed from further analysis. The three government items (city, county, state), taken together, had very high reliability ($\alpha = 0.904$). As such, they were averaged together into a single 'trust in government' index (M = 3.10, SD = 1.059). Trust in firefighters (M = 4.40, SD = 0.791), medical providers (M = 4.06, SD = 0.951), and police (M = 3.16, SD = 1.330) were retained as single items for analysis. For a summary of descriptive statistics (count and percent) for each variable question and response category, see Table 2.

Independent measures

Disability. Participants were asked a series of demographic questions, including whether they or someone they live with experienced some form of disability. Disability categories were taken from prior work [34] and participants were asked to select all that applied. Disability types reported by participants included physical disabilities (n = 318, 22.5%), learning disabilities (n = 147, 10.4%), neurological disabilities (n = 136, 9.6%), psychosocial disabilities (n = 131, 9.3%), hearing disabilities (n = 127, 9.0%), vision disabilities (n = 88, 6.2%), intellectual disabilities (n = 70, 4.9%), and other (n = 55, 3.9%). The number of disabilities reported per household ranged from zero (n = 828, 58.5%) to seven (n = 5, 0.4%). For clarity of analysis, all disability categories were collapsed, and participants were designated as either experiencing one or more disabilities in their household (41.5%, n = 588) or not experiencing disability (n = 828,58.5%).

Poverty. Participants were asked to indicate their entire household income before taxes and were provided the following response options: less than $25,000 (n = 288, 20.3%); $25,000 - $50,000 (n = 368, 26.0%); $50,000-$75,000 (n = 266, 18.8%); $75,000 - $100,000 (n = 204, 14.4%); and more than $100,000 (n = 290, 20.5%). The 2023 federal poverty guideline for a family of three is an annual household income of $24,860 [85]. We did not collect data on family size, so we assumed it was average for all participants (approximately three persons per

Table 2. Descriptive statistics for dependent variable question & response categories.

Anticipated Harm

"If a heat wave happened in your city, how much, if at all, do you think it would harm each of the following?"

	Response Category	(n)	%
Your health.	None at all (1)	183	12.9
	A little [2]	453	32.0
	A moderate amount (3)	396	28.0
	A lot (4)	208	14.7
	A great deal (5)	149	10.5
	Not sure (removed)	27	1.9
The health of others in your family.	None at all (1)	165	11.7
	A little (2)	414	29.2
	A moderate amount (3)	403	28.5
	A lot (4)	221	15.6
	A great deal (5)	161	11.4
	Not sure (removed)	52	3.7
The health of others in your community.	None at all (1)	17	1.2
	A little (2)	209	14.8
	A moderate amount (3)	463	32.7
	A lot (4)	381	26.9
	A great deal (5)	304	21.5
	Not sure (removed)	42	3.0

Comparative Need

"We want to know more about how prepared you feel you are to respond to an environmental emergency. Environmental emergencies might include things like wildfires, heat waves, severe air pollution, or other extreme weather events. How much do you agree or disagree with each of the following statements?"

	Response Category	(n)	%
"I need to get emergency information before other people."	Strongly disagree (1)	141	10
	Disagree (2)	278	19.6
	Neither disagree nor agree (3)	578	40.8
	Agree (4)	291	20.6
	Strongly agree (5)	87	6.1
	Not sure (removed)	41	2.9
"It takes me longer to respond in the event of an emergency compared to other people."	Strongly disagree (1)	277	19.6
	Disagree (2)	394	27.8
	Neither disagree nor agree (3)	336	23.7
	Agree (4)	269	19.0
	Strongly agree (5)	106	7.5
	Not sure (removed)	34	2.4
	Response Category	**(n)**	**%**
"I have a greater need for support during an emergency than other people."	Strongly disagree (1)	340	24.0
	Disagree (2)	349	24.6
	Neither disagree nor agree (3)	302	21.3
	Agree (4)	254	17.9
	Strongly agree (5)	147	10.4
	Not sure (removed)	24	1.7

(*Continued*)

Table 2. (Continued)

Trust in First Responders "How much do you trust or distrust the following groups to take care of people like you during an environmental emergency, like a heat wave or period of heavy wildfire smoke?"			
	Response Category	**(n)**	**%**
Your City Government	Completely distrust (1)	144	10.2
	Somewhat distrust (2)	289	20.4
	Neither trust nor distrust (3)	342	24.2
	Somewhat trust (4)	495	35.0
	Completely trust (5)	117	8.3
	Not sure (removed)	29	2.0
Your County Government	Completely distrust (1)	144	10.2
	Somewhat distrust (2)	264	18.6
	Neither trust nor distrust (3)	354	25.0
	Somewhat trust (4)	501	35.4
	Completely trust (5)	119	8.4
	Not sure (removed)	34	2.4
Oregon State Government	Completely distrust (1)	198	14.0
	Somewhat distrust (2)	245	17.3
	Neither trust nor distrust (3)	330	23.3
	Somewhat trust (4)	499	35.2
	Completely trust (5)	113	8.0
	Not sure (removed)	31	2.2
Police	Completely distrust (1)	222	15.7
	Somewhat distrust (2)	244	17.2
	Neither trust nor distrust (3)	245	17.3
	Somewhat trust (4)	455	32.1
	Completely trust (5)	228	16.1
	Not sure (removed)	22	1.6
Medical Providers [doctors, nurses, emergency personnel, etc.]	Completely distrust (1)	31	2.2
	Somewhat distrust (2)	77	5.4
	Neither trust nor distrust (3)	179	12.6
	Somewhat trust (4)	608	42.9
	Completely trust (5)	512	36.2
	Not sure (removed)	9	0.6
Firefighters	Completely distrust (1)	12	0.8
	Somewhat distrust (2)	28	2.0
	Neither trust nor distrust (3)	114	8.1
	Somewhat trust (4)	476	33.6
	Completely trust (5)	772	54.5
	Not sure (removed)	14	1.0

Note: Percentages displayed are rounded to the nearest tenth of a percent.

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household) [26]. As such, participants indicating that their household income was less than $25,000 per year were designated as living in poverty (n = 288, 20.3%).

Race. Mirroring the population of the city of Portland, the majority of survey participants were white. Because other racial categories were comparatively small when analyzed on their own, participants who indicated a race or ethnicity other than white (n = 339, 23.9%) were combined into a single group, and compared to participants who indicated they were white (n = 1077, 76.1%).

Compounding vulnerability. To quantify the influence of compounding vulnerability on risk perception, participants were given a 'vulnerability indicator score' that combined whether they or someone in their household had a disability, whether they lived in poverty, or whether they were a race other than white. This resulted in a score for each participant ranging from 0 (being white, having no disabilities, and living above the poverty line) to 3 (being non-white, disabled, and living in poverty). 38% of participants had zero vulnerability indicators (n = 538), 41.5% had one vulnerability, (n = 588), 17.2% had two vulnerabilities (n = 243), and 3.3% had three vulnerabilities (n = 47). Because those with all three vulnerability indicators were a comparatively small group, they were combined with those having two vulnerability indicators to increase the robustness of statistical analyses. This resulted in three groups for comparison: those with zero vulnerability indicators (n = 538, 38%), those with one vulnerability indicator (n = 588, 41.5%), and those with two or three vulnerability indicators (n = 290, 20.5%). A summary of vulnerability group characteristics is available in Table 1.

Results

Hypothesis 1 stated: "The more vulnerability indicators a person has, the more they will anticipate being harmed by extreme heat." To test this hypothesis, a one-way ANOVA was run comparing the three groups in terms of their anticipated harm. ANOVA results were significant [$F(2, 1404) = 22.326$, $p<0.001$], such that the more vulnerability indicators one had, the more they anticipated being harmed by extreme heat. A Tukey HSD post-hoc analysis revealed significant differences between all three groups. Those with zero vulnerability indicators ($M = 2.85$, $SD = 0.970$) anticipated significantly less harm from extreme heat compared to those with one vulnerability indicator ($M = 3.10$, $SD = 1.003$) ($p<0.001$) and those with two or more vulnerability indicators ($M = 3.31$, $SD = 0.932$) ($p<0.001$). Similarly, those with only one vulnerability indicator anticipated significantly less harm from extreme heat compared to those with two or more vulnerability indicators ($p<0.01$). Thus, hypothesis 1 was supported.

Hypothesis 2 stated: "The more vulnerability indicators a person has, the more (comparative) needs they will have in the event of an environmental emergency like extreme heat." To test this hypothesis, a one-way ANOVA was run comparing the three groups in terms of their anticipated comparative needs during an environmental emergency. ANOVA results were significant [$F(2, 1404) = 34.355$, $p<0.001$], such that the more vulnerability indicators one had, the more comparative need they had. A Tukey HSD post-hoc analysis revealed significant differences between all three groups. Those with zero vulnerability indicators ($M = 2.54$, $SD = 0.929$) anticipated having comparatively fewer needs than those with one vulnerability indicator ($M = 2.80$, $SD = 0.884$) ($p<0.001$) and those with two or more vulnerability indicators ($M = 3.07$, $SD = 0.884$) ($p<0.001$). Similarly, those with only one vulnerability indicator anticipated having comparatively fewer needs than those with two or more indicators ($p<0.001$). Thus, hypothesis 2 was supported.

Hypothesis 3 stated: "The more vulnerability indicators a person has, the less trust they will have in first responders to take care of people like them in the event of an environmental emergency like extreme heat, including (a) government, (b) firefighters, (c) medical providers, and

(d) police." To test this hypothesis, a one-way ANOVA was run comparing the three groups in terms of their level of trust for each of the first responder categories. ANOVA results comparing trust in government were significant [$F(2, 1397) = 6.975$, $p<0.001$], such that the more vulnerability indicators one had, the less trust they had that the government would take care of people like them in the event of an environmental emergency. A Tukey post-hoc analysis revealed significant differences between those with zero vulnerability indicators ($M = 3.22$, $SD = 1.029$) and those with two or more vulnerability indicators ($M = 2.93$, $SD = 1.044$) ($p<0.001$). The difference between those with zero indicators and those with one indicator ($M = 3.08$, $SD = 1.083$) was not significant ($p = 0.088$), nor was the difference between those with 1 vulnerability indicator and those with 2 or more ($p = 0.114$). Thus, hypothesis 3a was partially supported.

ANOVA results comparing trust in firefighters were significant [$F(2, 1399) = 16.002$, $p<0.001$], such that the more vulnerability indicators one had, the less trust they had that firefighters would take care of people like them in the event of an environmental emergency. A Tukey post-hoc analysis revealed significant differences between those with zero vulnerability indicators ($M = 4.51$, $SD = 0.687$) and those with 2 or more vulnerability indicators ($M = 4.18$, $SD = 0.947$) ($p<0.001$), but found no significant difference between those with zero vulnerability indicators and those with one indicator ($M = 4.42$, $SD = 0.778$) ($p = 0.152$). There was also a significant difference between those with one vulnerability indicator and those with two or more indicators ($p<0.001$). Thus, hypothesis 3b was partially supported.

ANOVA results comparing trust in medical providers were significant [$F(2, 1404) = 22.197$, $p<0.001$], such that the more vulnerability indicators one had, the less trust they had that medical providers would take care of people like them in the event of an environmental emergency. A Tukey post-hoc analysis revealed significant differences between all three groups. Those with zero vulnerability indicators ($M = 4.22$, $SD = 0.866$) had significantly more trust in medical providers than those with one vulnerability indicator ($M = 4.07$, $SD = 0.938$) ($p<0.05$) and those with two or more indicators ($M = 3.76$, $SD = 1.057$) ($p<0.001$). Similarly, those with one vulnerability indicator had significantly more trust than those with two or more ($p<0.001$). Thus, hypothesis 3c was supported.

Finally, ANOVA results comparing trust in police were significant [$F(2, 1391) = 24.934$, $p<0.001$], such that the more vulnerability indicators a person had, the less trust they had that police would take care of people like them in the event of an environmental emergency. A Tukey post-hoc analysis revealed significant differences between all three groups. Those with zero vulnerability indicators ($M = 3.42$, $SD = 1.230$) had significantly more trust in firefighters than those with one vulnerability indicator ($M = 3.13$, $SD = 1.326$) ($p<0.001$) and those with two or more indicators ($M = 2.74$, $SD = 1.407$) ($p<0.001$). Similarly, those with one vulnerability indicator had significantly more trust than those with two or more ($p<0.001$). Thus, hypothesis 3d was supported.

For a summary of all one-way ANOVA results, see Table 3. For graphs depicting the mean differences between the three vulnerability groups compared to overall sample means for all dependent variables, see Figs 1–6.

Discussion

Extreme heat has proven to be a formidable climate threat for metropolitan areas with numerous deleterious effects, including infrastructure damage, power grid interruptions, and threats to human health. Like in many cities, the effects of extreme heat in Portland, Oregon are inequitably distributed, with prior research demonstrating that PWD, those living in poverty, and racial minorities face an increased risk. This study sought to better understand extreme heat

Table 3. Descriptive and ANOVA statistics for anticipated harm, comparative need, and trust in first responders by number of vulnerability indicators.

Hypothesis 1: The more vulnerability indicators one has, the more they will anticipate being harmed by extreme heat.

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	2.85	0.970	22.326	<0.001
1	3.10	1.003		
2+	3.31	0.932		

Hypothesis 2: The more vulnerability indicators one has, the more (comparative) needs they will have in the event of an environmental emergency like extreme heat.

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	2.54	0.929	34.355	<0.001
1	2.80	0.884		
2+	3.07	0.884		

Hypothesis 3: The more vulnerability indicators one has, the less trust they will have in first responders to take care of people like them in the event of an environmental emergency like extreme heat.

H3a: Government

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	3.22	1.029	6.975	<0.001
1	3.08	1.083		
2+	2.93	1.044		

H3b: Firefighters

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	4.51	0.687	16.002	<0.001
1	4.42	0.778		
2+	4.18	0.947		

H3c: Medical Providers

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	4.22	0.866	22.197	<0.001
1	4.07	0.938		
2+	3.76	1.057		

H3d: Police

Vuln. Indic.	Group Mean	Group SD	F	ANOVA Alpha (p)
0	3.42	1.230	24.934	<0.001
1	3.13	1.326		
2+	2.74	1.407		

https://doi.org/10.1371/journal.pclm.0000386.t003

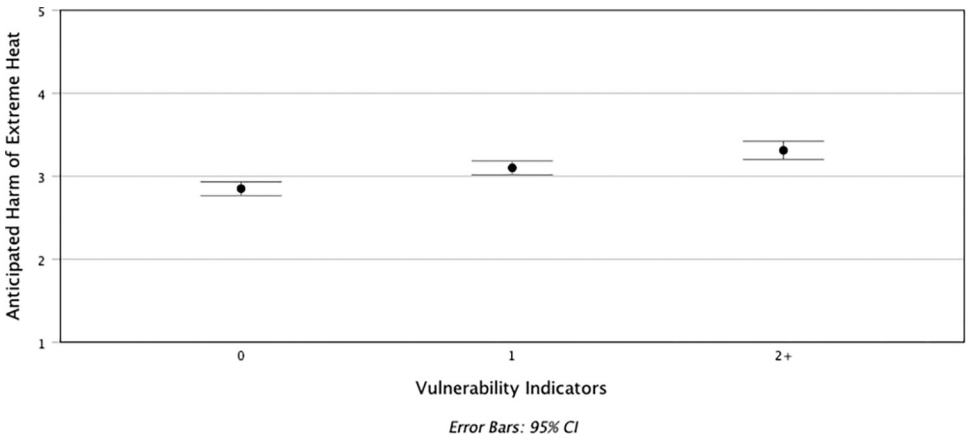

Fig 1. Anticipated harm of extreme heat.

https://doi.org/10.1371/journal.pclm.0000386.g001

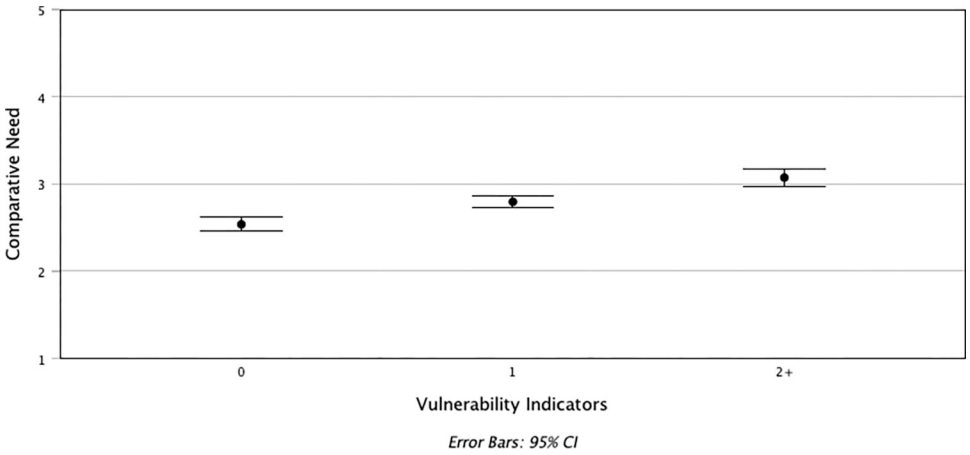

Fig 2. Comparative need.

https://doi.org/10.1371/journal.pclm.0000386.g002

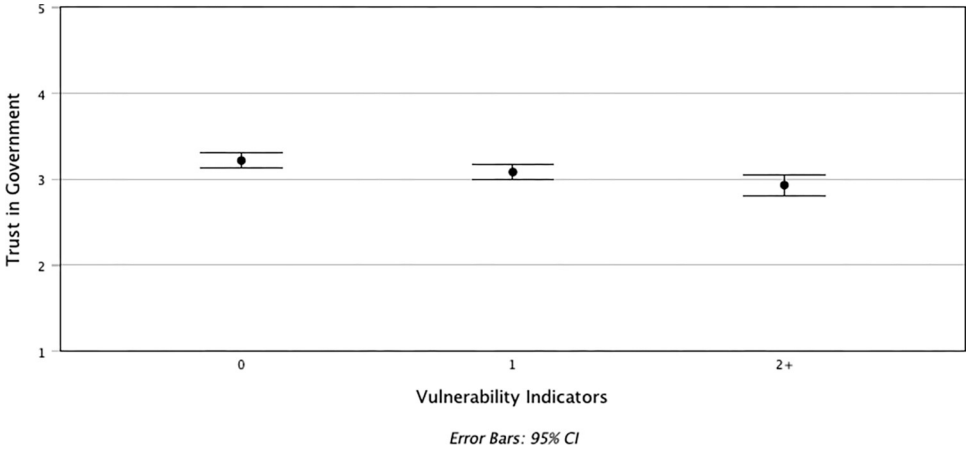

Fig 3. Trust in government.

https://doi.org/10.1371/journal.pclm.0000386.g003

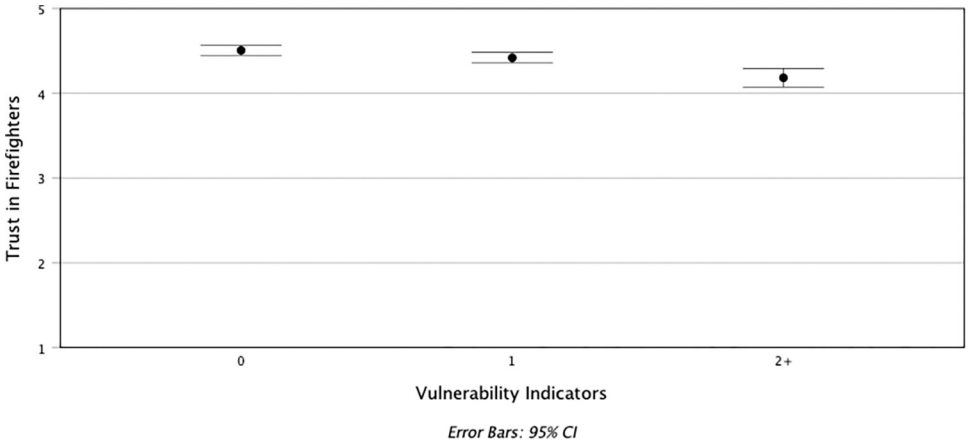

Fig 4. Trust in firefighters.

https://doi.org/10.1371/journal.pclm.0000386.g004

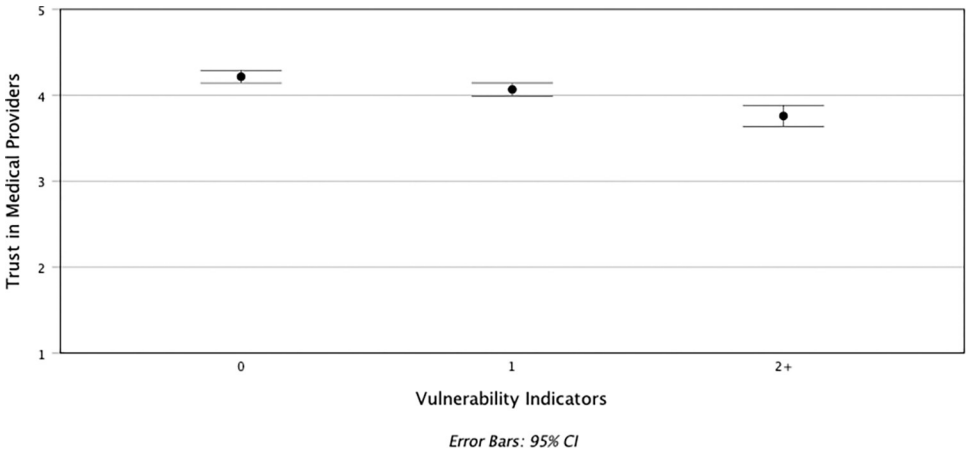

Fig 5. Trust in medical providers.

https://doi.org/10.1371/journal.pclm.0000386.g005

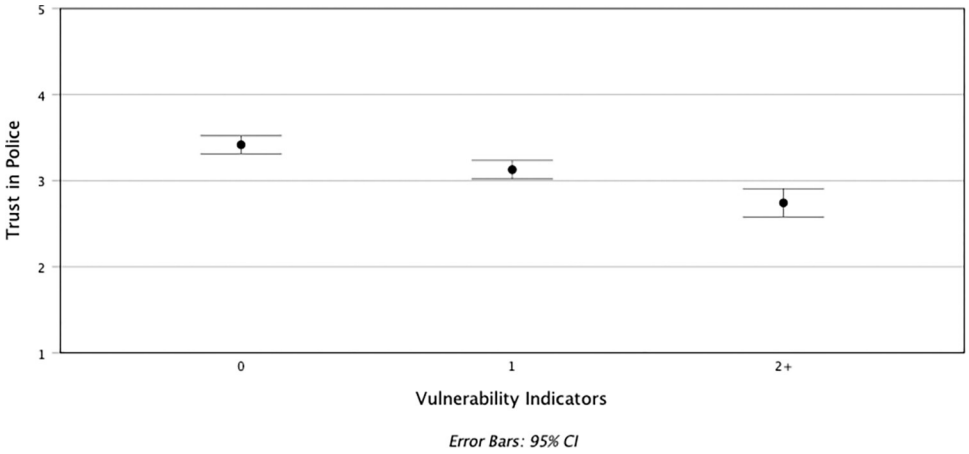

Fig 6. Trust in police.

https://doi.org/10.1371/journal.pclm.0000386.g006

risk perceptions, environmental emergency response needs, and level of trust in first responders among residents of the Portland Metro Area. Results suggest a compounding influence of disability, poverty, and race on public perception surrounding extreme heat and environmental emergencies. We observed that an increased number of vulnerability indicators is associated with greater anticipated harm from extreme heat, higher anticipated need in the event of an environmental emergency, and lower trust in first responders. We also found that trust in firefighters and medical providers was comparatively high for those with two or more vulnerability indicators.

The current study supports prior work by showing that PWD, those in poverty, and racial minorities perceive themselves as being more at risk from extreme heat [36,47], having increased needs in the face of environmental emergencies [34,37,48], and commonly having negative perceptions of and experiences with the groups most responsible for aiding them in the event of an environmental emergency [38,39,49,50,62,64,66]. Distrust in police and government for vulnerable groups has been explored by previous research. This work highlights the important role of systemic failures in the creation of distrust for vulnerable groups. For example, distrust of government among racial minorities has been attributed to the criminal

justice system being more visible and intrusive in their everyday lives [86]. Similarly, mistrust in police has been shown to be related to structural disadvantages of those living in poverty, including reduced mobility and social cohesion [87]. For PWD, distrust in government has been attributed to issues including poor communication with care providers and the frequent errors that occur in welfare systems [88].

These results offer an important extension of prior literature by illustrating that these vulnerabilities may have a compounding influence on public perception. They further imply that more detailed demographic assessments are required for successful vulnerability-inclusive disaster planning. Future social scientific research should focus on the previously overlooked impacts of compound vulnerabilities to extreme climate events.

(Compounding) vulnerability-inclusive disaster planning

Vulnerabilities to climate extremes are often considered in isolation. Prior work has highlighted that response strategies often fail to take into account the needs and perspectives of PWD [31,89–92]. Similarly, previous scholarship has argued that those living in poverty are not only uniquely vulnerable to climate extremes, but that their unique needs are often not sufficiently considered and accounted for in disaster planning [22,93,94]. Studies examining the relationship between race and disaster recovery have shown that communities of color similarly face unique needs when exposed to disasters [95] and are commonly excluded from disaster and risk planning. The current study highlights that these vulnerabilities have a compounding effect, so that the more vulnerability indicators a person has, the more at risk they feel, the more comparative needs they anticipate having, and the less they trust first responders to take care of people like them. Efforts to engage vulnerable groups in disaster planning thus need to take into consideration the potential for co-vulnerabilities to climate extremes. Based on prior work and the current study, we offer the following recommendations for public engagement efforts surrounding extreme heat in Portland, Oregon:

Increase communication with vulnerable groups regarding protective actions. Prior work has demonstrated, and this study confirms, that vulnerable groups often have increased risk perceptions in line with their increased vulnerability. The current study suggests that overlapping vulnerability indicators increases the anticipated harm from extreme heat events. In light of these results, public engagement efforts surrounding extreme heat should take groups with co-vulnerabilities into account. Specifically, communication efforts regarding response options for these groups should be increased to enhance their sense of self- and response-efficacy. Responding to the increased risk perceptions among these groups with increased communication regarding protective actions will help ensure their threat perceptions are a catalyst for protective action, rather than an immobilizing force [96].

Engage vulnerable groups to accommodate their higher comparative needs. The current study did not investigate the specific needs of vulnerable groups. However, understanding what these unique needs are in advance of an emergency, and strategizing to meet those needs, should be a high priority for those involved in engagement and response efforts. This is especially important for individuals with co-vulnerabilities, as their needs will likely be multifaceted and complex compared to those with no (or one) vulnerability.

Establish lines of communication between vulnerable groups and first responders. In order to make disaster plans more inclusive, it's imperative that organizations responsible for emergency response–including government representatives, police, firefighters, and health care workers–are responsive to the needs and perspectives of these groups. Their ability to be more responsive is dependent upon the extent to which the vulnerable feel that they can rely on them in the event of an environmental emergency. The current study suggests that the

more vulnerability indicators a person has, the less they trust government representatives, firefighters, medical providers, and police to take care of people like them in the event of an environmental emergency. Importantly, trust in firefighters was comparatively high across all vulnerability groups. While those with two or more indicators had significantly less trust in firefighters than those with zero vulnerability indicators, even this group had fairly high trust (M = 4.18 on a 5-point scale). The same pattern was evident for medical providers, although it was comparatively lower than trust in firefighters among the most vulnerable (M = 3.76 on a 5-point scale). These results suggest the potential for these two groups to function as trusted resources for PWD, people experiencing poverty, and racial minorities in the event of an environmental emergency. Efforts aimed toward community engagement should nurture these areas of comparatively high trust, while taking care to foster and improve trust between vulnerable groups, government representatives, and police.

We are aware that these recommendations are difficult to implement. Vulnerability-inclusive disaster planning can be exceptionally challenging even when vulnerabilities are considered in isolation [97,98]. For example, vulnerable individuals may experience greater social isolation, may lack adequate resources to invest in disaster preparation, and their locations within communities may be less well-known to first responders. Additionally, emergency response agencies, such as counties, face internal barriers including limited funding and staff and a plethora of other demands on time and resources [22]. We understand, then, that considering compounding vulnerabilities in disaster planning in addition to singular vulnerability categories is a tall order. However, fine-tuning disaster response remains a vital component to disaster planning that aims to be responsive to the needs of those most at risk.

Limitations & recommendations for future research

There are several limitations of the current study. First, our participants were recruited through Survey USA and consisted of individuals who had previously agreed to take part in online survey research. As such, we excluded those who do not have interest in or access to online surveys. Similarly, our study relied exclusively on self-reported data. It is thus possible that participants misrepresented or exaggerated their opinions or succumbed to social desirability bias when answering survey questions. Second, when measuring disability, we asked participants if they *or someone they live with* currently had a disability. While we did so intentionally (as disaster response often happens at the household level), this likely inflated the number of people in our sample who were designated as having a disability. Future work should differentiate between the two. Third, we focused only on three vulnerability indicators relevant to extreme heat–disability, poverty, and race. We did not include other indicators, like age or geographic characteristics of surrounding landscapes. Future work should integrate age and biophysical characteristics of urban environments to examine the extent to which these variables exacerbate the compounding vulnerability observed in the current study.

Supporting information

S1 File. Full questionnaire.
(DOCX)

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Conceptualization: Brianne Suldovsky, Molly Baer Kramer, Jonathan Fink.

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Project administration: Molly Baer Kramer.

Supervision: Jonathan Fink.

Visualization: Brianne Suldovsky.

Writing – original draft: Brianne Suldovsky.

Writing – review & editing: Molly Baer Kramer, Jonathan Fink.

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