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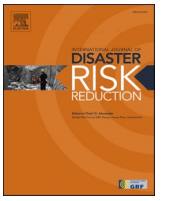

Recommendations for increasing the reach and effectiveness of heat risk education and warning messaging

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ABSTRACT

A growing number of national, state, and local governments are developing heat health warning systems and emergency preparedness plans to support the public in protecting against extreme heat. However, concern remains about the reach and effectiveness of these interventions in supporting protective action specifically among those individuals and communities most at-risk. We conducted four focus groups during spring and summer 2021 with 43 individuals who represent, serve, and/or are part of heat-vulnerable communities in San Diego County, California, to elicit recommendations for increasing the reach and effectiveness of heat risk education and warning messaging. Key recommendations include: (1) diversification of communication channels, (2) specification of content, and (3) development of formally coordinated campaigns. Grounded in local knowledge and experience, these recommendations align with evidence-based support for successful hazard risk communication as well as the increasing valorization of dialogic models of communication. In doing so, they highlight the need for heat-vulnerable communities to be involved in the planning and implementation of interventions meant specifically to support them in taking protective action. Here, we provide a detailed description of those recommendations so that they may be implemented and evaluated in future work and their transferability may be explored across other regions characterized by extreme heat.

1. Introduction

Heat is a deadly weather-related hazard worldwide, responsible for 7 per 100,000 excess deaths annually [1]. Globally, while heat-related excess deaths are fewer than cold-related excess deaths (67 per 100,000) [1], and more disaster-related deaths result from storms (39%) and drought (34%) [2], heatwaves can disproportionately impact regions and local areas. For example, heat is the deadliest weather-related hazard in the United States [3], and in the past 50 years, two heatwaves in Europe contributed to 80% of deaths resulting from weather-, climate-, and water-related disasters [2]. The exposure of populations to deadly heat is projected to increase substantially as the climate warms and becomes more humid [4]. Because heat-related illness and mortality are often preventable by taking protective action [5], successfully communicating heat risk to the public can be a highly effective way to save lives and reduce economic impacts [6–8]. A growing number of national, state, and local governments are developing heat health warning systems (HHWS) and emergency preparedness plans to support the public in protecting against extreme heat [9–13]. HHWS use forecasts of high-risk weather conditions to trigger public health warnings and in some cases government operational or service response (e.g., through enactment of an emergency preparedness plan) [14]. Emergency preparedness plans vary but include actions

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like ensuring continuity in utility service, providing home visits to at-risk individuals, and increasing the number of available emergency service personnel [15]. However, despite growth in both types of interventions, concern remains about their reach and effectiveness in supporting protective action specifically among those individuals and communities most at-risk [16–18].

There are numerous, often interconnected factors that influence vulnerability to extreme heat, including socioeconomics, age, occupation, physical disability, presence of preexisting conditions and comorbidities, and built environment [19–25]. For example, historically, mortality due to extreme heat has disproportionately affected older adults [19], while more recently, workplace heat exposure has begun to present an increasing challenge to occupational health and safety [25].

Here, we share recommendations for increasing the reach and effectiveness of heat risk education and warning messaging from individuals who represent, serve, and/or are part of heat-vulnerable communities in San Diego County, California. The human and physical geography of San Diego County make it ideal to study heat impacts. The 2020 resident population of San Diego County was 3,298,000 [26] and includes urban and rural communities situated in varied climate zones: coastal, mountain, and desert, implying that the population can be exposed to a range of heat magnitudes.

The recommendations from San Diego County were elicited during four focus groups, involving 43 participants, conducted virtually during spring and summer 2021. Key recommendations include: (1) diversification of communication channels, (2) specification of content, and (3) development of formally coordinated campaigns. We highlight how these recommendations, grounded in local knowledge and experience, align with evidence-based support for successful hazard risk communication as well as the increasing valorization of dialogic models of communication. These findings support others in advocating for the involvement of heat-vulnerable communities in the planning and implementation of interventions meant specifically to support them in taking protective action [17,27,28].

1.1. Background

Ongoing concern about the reach and effectiveness of HHWS and emergency preparedness plans in supporting protective action is related to a need for their evaluation to know whether the public is receiving, processing, and acting upon them [11,13,17,29,30]. Yet evaluation of these interventions can be difficult, and with some exception [12,15,29,31–33], is not often a component (or a reported component) of their development [9,14,34]. Challenges to evaluation include lack of health surveillance for heat wave mortality, emergency dispatches, hospitalizations, and hospital discharges [35]; difficulty establishing attribution where reduced morbidity and mortality are observed [9,14]; high numbers of variables precluding comparison between heatwaves and locations [14]; and limited resources and funding [36]. One recommendation for circumventing these challenges is to adjust the focus of evaluation, for example by considering not only the measurable outcomes (e.g., where possible, reduction in heat wave mortality) but also the functionality of an intervention [14]. For example, Kovats and Ebi [14] suggested that evaluation could focus on determining whether a HHWS is appropriate in lead-time and responsible agencies are communicating and cooperating effectively to implement it, or to determine whether the different components of a HHWS, like forecast and risk assessment, are accurate.

Another recommendation is to evaluate public awareness of the intervention and corresponding changes in individual and overall population behavior [29]. Where researchers have done so, they have found that awareness tends to be lower among more heat-vulnerable groups like the elderly, less educated, socially isolated, and those with both high heat-risk and high heat-exposure [16,37]. Researchers also found that when awareness has been high, it is often the case that the public reports it did not modify its behavior [16,38,39]. Both findings point to potential knowledge gaps between messengers (e.g., weather forecasters and public health officials) and receiver audiences (i.e., the public) that may limit the effectiveness of heat risk communication and delivery (see also [38,40–43]). They also point to potential linear assumptions in heat risk communication, for example that simply to inform people about an extreme heat event will increase their awareness and motivate behavioral response, or that to inform people about the benefits of mitigation strategies like cooling centers means these benefits are understood [17,44]. The persistence of knowledge gaps and reliance on linear assumptions can influence whether and how the public in general and heat-vulnerable groups in particular are reached through interventions, and whether and how they respond [17]. However, it is also important to note that even when knowledge gaps are closed, barriers to protective action may still exist [45]. For example, energy costs can impede the use of air conditioning, limited public transportation or high fuel prices can prohibit travel to cooling centers, and wage structure (e.g., piece rate in agriculture) can dissuade workers from taking breaks [46–48].

While overcoming the above and other barriers may require longer-term policy action, in the nearer-term researchers can assist messengers in closing knowledge gaps by generating insight into individual decision-making processes and behaviors through application of social and behavioral theoretical frameworks like the Health Belief Model (HBM), Mental Models Approach, and Protective Action Decision Model [11,49]. For example, applying the HBM to understand air-conditioning (AC) use among middle-aged and older adults with chronic heart problems, Richard et al. [50] found that beliefs about AC were more likely to determine use than was access. In another example, Williams and Grundstein [51] applied the Mental Models Approach to identify differences in beliefs about children left in hot cars. They found that specialists (e.g., epidemiologists and psychologists) emphasized that any parent/caregiver could commit this error while most parents/caregivers failed to acknowledge it as a self-possibility. If shared with messengers, such insights could help inform heat-related interventions to increase the likelihood of their effectiveness before (or in the absence of) evaluation.

There is also a history of hazard risk communication studies that offers numerous potentially transferrable recommendations and guidelines that could similarly inform heat-related interventions where they do not already [52–56]. Hazard risk communication is considered a critical component in disaster risk reduction, particularly in the design and implementation of early warning systems [55,57]. Much of the work in hazard risk communication has been aligned closely with the requirements of government agencies that have a mandate to protect the public [56]. Recommendations and guidelines for successful hazard risk communication address questions of

purpose, strategy, content, style, audience, source, trust, uncertainty, and dissemination, among others [52,54,55]. Relatedly, interactive, dialogic models of hazard risk communication are becoming increasingly valorized as a means for informing aspects of that specificity and ensuring its effectiveness [27,58–61]. These models differ from more traditional linear (or "top-down") approaches to hazard risk communication wherein messaging can be misaligned with public concerns and capacity for mitigation [27]. Instead, they foster "interaction" and "dialogue" between messengers and receivers, leading to more meaningful communication as each group can learn from and inform the other [27]. Messengers are therefore encouraged to build social capital (or links to and relationships) with receivers to enable critical interaction and dialogue to take place [27].

2. Methods

2.1. Study context

To highlight regional San Diego County thermal climate conditions during the warm season (1 June–30 September), we performed calculations using daily, 6 km horizontal resolution estimates of maximum temperature spanning 1979–2021 using the gridMET product [62]. This analysis was performed with the goal of creating a more nuanced understanding of how temperature patterns vary in space and to provide additional context and insight for the interpretation of heat-health hazards across a landscape characterized by diverse physical and social geographies. The proximity of coastal communities to the cool Pacific Ocean and its shallow marine layer moderates the warm season median maximum temperatures (less than 30 °C; Fig. 1a). However, this influence declines with distance inland and with elevation leading to median maximum temperatures exceeding 40 °C (Fig. 1a). The temperature differences between a typical hot day during the warm season (defined as the 5% of hottest days) and the median maximum temperature increase with distance inland (Fig. 1a). For already hot inland mountain and desert regions in the central and eastern portions of San Diego County, this implies thermal comfort declines further in interior regions. Coastal communities, however, are more susceptible to extreme heat that may be notably different from that to which populations are acclimated or have the ability to manage [63]. Temperature differences between the all-time hottest 10% of warm season days and median maximum temperatures are greatest along the coast (Fig. 1b). These results indicate how heat impacts, like physical geography, are varied across San Diego County: hot days in hot locations push thermal comfort limits (Fig. 1a) while extreme heat can be amplified in characteristically cooler coastal regions and may push the thermal comfort of less adapted populations (Fig. 1b).

The National Weather Service (NWS) Weather Forecast Office San Diego (NWS San Diego) currently uses ambient temperature thresholds and the Heat Index, which combines temperature and relative humidity, to issue heat alerts and guide heat risk communication [64]. Issuance criteria and approaches to heat risk messaging vary geographically and by each NWS Weather Forecast Office, as each office has license to set local criteria with input from partner agencies [65,66]. In the past five years, NWS San Diego has issued dozens of heat alerts (heat advisories, excessive heat watches, and excessive heat warnings) annually over its county warning area, which includes Orange, San Bernadino, Riverside, and San Diego counties. In a given year, the total number of heat alerts ranges from 6 to 29 with the variance resulting from event frequency and duration [67]. Over the past years, there has also been growing interest and momentum at the state, county, and local government levels, as well as within academic institutions and nonprofit organizations, to better understand, mitigate, and adapt to the impacts of extreme heat and other climate-related hazards [63,68–74]. For example, at the state level, California produced its first comprehensive climate change assessment in 2006, with subsequent assessments in 2009, 2012, and 2018, and a fifth assessment planned to commence in 2022 [75]. In another example, in April 2022 California released a statewide action plan outlining established (either completed, ongoing, or forthcoming) and new recommended actions toward: increasing public awareness and notification about extreme heat, strengthening community services and response, adapting working lands and the built environment, and protecting natural environments [76]. The plan is guided by extensive public input and serves as an update to the initial recommendations developed in 2013 [77].

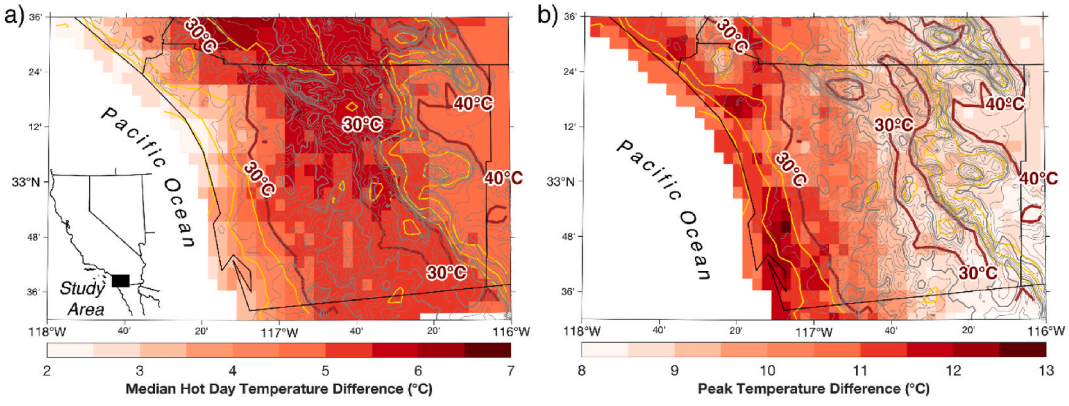

Fig. 1. (a) Median temperature difference (in °C) between the hottest 5% of days and the median maximum temperature. (b) Maximum (peak) temperature difference (in °C) between the all-time hottest 10% of days and median maximum temperature. On both (a–b), grey lines show topographic contours (contour interval 100 m; thick grey denotes 500 m contours). Gold contours denote 2 °C isotherms and thick dark red contours denote 10 °C isotherms. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.2. Methodological approach

To elicit recommendations for increasing the reach and effectiveness of heat risk education and warning messaging from individuals who represent, serve, and/or are part of heat-vulnerable communities, we conducted four focus groups between March and June 2021 in San Diego County. Each focus group included between five and 16 participants (n = 43 total) recruited via email through County of San Diego Health and Human Services Agency and Office of Border Health partner networks (see Ref. [78]). The authors were guided by the literature in determining the number of participants per focus group and the number of focus groups total. Bernard [78] recommends between six and twelve participants per focus group [78]. This is to reduce the potential for a few voices to dominate in smaller groups and for facilitation to become difficult in larger groups [78]. Often the majority of themes are identified within the first two to three focus groups [79].

Focus group participants included community leaders and advocates (n = 12) as well as representatives of nonprofit and community-based organizations (n = 12), county and city government agencies (n = 8), healthcare professions (n = 8), schools and universities (n = 2), and a utility company (n = 1). Many participants were also part of the same heat-vulnerable communities they serve. Each focus group lasted 90 min and was conducted virtually over the teleconferencing platform, Zoom, for the safety of participants during the COVID-19 pandemic. Each focus group was also audio-recorded and transcribed. Simultaneous (English-Spanish) translation was provided for one focus group wherein Spanish was the primary or only language spoken by the majority of participants. All other focus groups were conducted in English. Guiding discussion questions were informed by related literature and included: (1) Is heat (as it relates to daytime and/or nighttime temperatures) a health concern in the communities you live in and/or serve (why/why not)? (2) What (if any) heat-health education and/or warning messaging programs exist in or reach those communities, and what is their effect (e.g., do they motivate protective action)? (3) What opportunities and barriers exist for local communities to protect against heat? (4) How can those opportunities be fostered and/or what is needed to overcome those barriers?

Following a grounded-theory approach [78], the lead author used in-vivo techniques to code the transcripts in the qualitative analysis software application, Dedoose. Once an initial codebook was developed, it was reviewed by and discussed with the second author to clarify ambiguities and establish agreement in the use of the codes [78,80]. Examples of codes include “heat-health concerns, ” “distribution of impacts,” and “protections and mandates.” The same two authors then reviewed the data under each code to identify patterned themes (e.g., lack of heat risk education) and corresponding recommendations (e.g., develop peer-trainer heat risk education curriculum) [81]. We acknowledge that the recommendations may not be representative or exhaustive of all agencies, organizations, and communities within San Diego County. However, our intention has been to provide initial insight into opportunities and barriers for increasing the reach and effectiveness of heat risk education and warning messaging from the perspectives of representatives and members of heat-vulnerable communities. Additional inquiry would be required to assess the generalizability of these opportunities and barriers across communities within and beyond San Diego County.

3. Results

Participants agreed collectively that heat is a health concern, particularly for those individuals for whom demographic (e.g., age), health (e.g., underlying conditions), economic (e.g., houselessness, access to AC or the ability to run it), occupational (e.g., outdoor employment) and other (e.g., physical disability) factors may make them more vulnerable. However, they generally perceived there to be a lack of public education about heat risk, at least to which they have been exposed, and only a few were aware of or recalled having encountered heat warning messaging. For that reason, participants indicated a strong interest in becoming educated about heat risk and in being able to educate others. Knowledge gaps they identified in need of addressing include: What constitutes “extreme” (or unsafe) heat and how might it vary for different population groups (e.g., considering age and prevalence of chronic disease) and across geographic areas (e.g., considering county microclimates (Fig. 1)? What are the potential health impacts of heat, how might they vary, and how can they be mitigated? What are the symptoms of those health impacts and how can they be recognized? What are the occupational safety rights regarding heat for indoor and outdoor workers, and do they vary according to the status of a worker as permanent, seasonal, or undocumented?

Several participants acknowledged that to inform the public about a particular hazard risk does not guarantee that people will change their behavior according to advice. However, they did view increasing the reach and effectiveness of heat risk education and warning messaging as important for generating awareness among those who might. As one participant commented, “The idea that you’ve lived here forever doesn’t mean that you haven’t actually suffered heat symptoms or had heat complications. […] I think painting that picture of what the signs and symptoms [are] for people to look out for is a key component to get them to realize that something is actually happening to them in a heat wave, and then they might take it more seriously.” Recommendations from participants about how to increase the reach and effectiveness of heat risk education (or to close the identified knowledge gaps) and warning messaging are described in sections 3.1-3.4.

3.1. Increasing the reach of heat risk education and warning messaging

To increase the reach of heat risk education and warning messaging, participants recommended diversifying communication channels to include not only the National Weather Service, county and local government agencies (e.g., County of San Diego Health and Human Services Agency and Partner Relay Network), television, radio, and other news and social media, but also existing networks like those comprising nonprofit and community-based organizations, neighborhood schools, peer-trainer and health outreach and engagement programs, and community and religious leaders among other trusted messengers. Many of the organizations and individuals within these networks have high levels of social capital, cultural competence, and extensive reach within the communities they serve. This makes them especially well-positioned to connect people to existing resources (e.g., from NWS San Diego), advise on or

assist with the translation of those same (or other) resources into different languages, and "meet people where they are." A participant explained of the latter point, "You can connect better with the community if someone who looks like them or speaks the language can provide the information. I think that's very vital. Or someone that you actually know and interact with on more of a regular basis, like a church or anywhere else people attend. […] You're going to trust someone that you know or you see more often." Many of the organizations and individuals within these networks can also provide opportunities for the direct integration of heat risk education and warning messaging into established information and communication programs. Some of these programs serve as conduits of general information, for example from neighborhood schools to parents and families. Others serve as conduits specifically for health outreach and engagement, for example from clinics and health workers to farmworker and migrant communities.

Based largely on in-person (or virtual) interaction and the dissemination of information by word-of-mouth, health outreach and engagement programs are perceived to be more effective in educating communities than is the dissemination of information via written materials (e.g., fliers and pamphlets), though varied means are often used complementarily. Participants explained that heat risk education could be integrated into these programs by having subject matter experts educate community members directly. It could also be integrated by having subject matter experts train community health workers, leaders, and other trusted messengers in heat risk education, equipping them to disseminate information within local communities and to train others with similar capacity to do the same. To reach at-risk populations that may not currently be served through existing health outreach and engagement programs, participants explained that there are other opportunities to "meet people where they are." For example, one health promoter reported that her organization partners with food pantries to host health fairs and that similar opportunities could be facilitated to help educate the public about heat. Participants also posed the question of whether the reach of heat risk education should be extended into schools, with some recalling the effectiveness of the hazard risk education (e.g., tornado warning procedures) they received as children in other parts of the US.

3.2. Increasing the effectiveness of heat risk education and warning messaging

Again, few participants were aware of or recalled having encountered heat warning messaging. However, many shared the opinion that hazard risk communication often lacks the comprehensiveness of detail, population and geographic specificity (Fig. 1), diversity in language and format, and lead-time to be effective in informing the public and supporting protective action. As one participant explained: "When the power goes out, for example, people go to the [utility] website and they're trying to find out how long is the outage going to be? What to do? Where are the cool zones? None of that is in Somali language, in Arabic. So, we have a lot of people who are just confused. They're just wondering what's going on. And yes, again, it usually is right in the middle of when it's already happened when people are trying to figure it out." To increase the effectiveness of heat risk education and warning messaging, participants therefore recommended a shift from more generalized (e.g., "stay hydrated") to comprehensive and specific content, for example that:

(1) uses locally defined metrics to make clear which geographic areas or populations within those areas may be most vulnerable to heat risk and why (e.g., by providing data from socioeconomic and spatial analyses of heat burden);
(2) is explicit about the potential health impacts (and their symptoms) to at-risk populations and/or in specific geographic areas;
(3) provides clear recommended actions for mitigating those health impacts, including at individual, household, and community levels;
(4) is available in different languages and formats (e.g., storytelling and short video) to ensure information equity; and
(5) is culturally competent (e.g., clarifies misconceptions and dispels myths) to enhance uptake.

Participants also noted that to increase the effectiveness of heat risk education and warning messaging promises to increase the likelihood that it is shared. As in one example, "We have families that just arrived from refugee camps, and they weren't in traditional schooling, so getting the messaging across is most effective in the form of videos […] and they will share that video, and it would be a lot more effective than mailing out pamphlets. It would be a lot more effective than expecting people to happen to come across it in the news." Finally, participants also suggested that the above recommendations (sections 3.1, 3.2) be integrated into a formally coordinated heat risk education and warning messaging campaign to address heat risk more proactively, as described below.

3.3. Developing a heat risk education and warning messaging campaign

Some participants, especially those who work in health professions, shared the perspective that public health is often approached reactively and focused more on detection than it is on prevention. For example, one health promoter commented, "We do work with farmworkers […] and we would go out to the farms, and we would do like a skin test because that community is impacted by skin cancer. […] They screen you for skin cancer, but what can we do to protect before it gets there?" Similarly, on the few occasions when participants had (or recalled having) encountered heat risk education or warning messaging, they considered it to be lacking in lead-time. This does not imply that all heat risk education and warning messaging in San Diego County lacks lead time. In some instances, participants may have been unaware of education and messaging leading up to a heat event. However, to increase the opportunities for the public to become knowledgeable about and prepared for heat risk, participants advocated for a proactive approach to heat risk education and warning messaging coordinated through formal campaigns. These campaigns would include the following activities: (1) in winter/spring, creation of training opportunities for key organizations and individuals to become educated about heat risk (see section 3) and integrated into existing communication channels (see section 3.1); (2) in spring/early summer, utilization of the expanded communication channels to conduct health outreach and engagement with heat-vulnerable communities; and (3) in summer, continued health outreach and engagement utilizing the expanded communication channels to remind vulnerable communities of

the potential for heat risk and to alert them to extreme heat throughout the warm season.

To the extent possible, these activities would be coordinated across networks so that both education and messaging content are iterative (i.e., to reinforce learning) and consistent (i.e., to ensure clarity and build trust). The activities would also be repeated annually or biennially so that new, interested organizations and individuals could be trained and integrated into communication channels. This would enhance public education over a longer timeframe. Participants emphasized that adopting a campaign approach could also help to create a single, unified "voice" about heat risk that resonates more strongly with the public than does potential misinformation. Of concern was that some groups may otherwise learn about heat risk from unofficial sources, for example on social media, especially if only those are communicating in their language.

3.4. Barriers to heat risk communication and mitigation

Despite their interest in and recommendations for increasing the reach and effectiveness of heat risk education and warning messaging, participants acknowledged that there are challenges to doing so. They noted barriers to communication like unfamiliarity with or difficulty using communication technologies (e.g., emergency preparedness apps and social media), limited English language proficiency, and lack of access to the internet, cellphones, and cellphone reception. One participant illustrated the latter point through anecdote, stating: "Getting WiFi [during the COVID-19 pandemic] was challenging for El Cajón families who are low-income because they didn't really have access to start with. I was working with the school district to hook them up with Starbucks parking lots so that they could do their education, but that doesn't really work when there's a crisis going on – you can't tell someone to go to a Starbucks in order to get the information." Participants also acknowledged barriers to mitigation like lack of air conditioning (or financial preclusion of its use), insurance, medical care, legal status (e.g., inhibiting workers from requesting breaks and seeking medical attention), livable wages (e.g., resulting in economic incentive to not take breaks), adequate public transportation (e.g., to get to cooling centers), green spaces, and shade. Given these challenges, they advocated for heat risk education to be directed not only toward at-risk groups but also toward decisionmakers. They stressed the need specifically for a comprehensive approach to addressing heat risk that combines public education with firm policy action for reducing the socioeconomic and other disparities that result in barriers to heat risk communication and mitigation, and that strives to create a more thermally-adapted built environment. As one participant commented, "I think in terms of where we go […] if I were to pick a word, it's about adaptation and the need to create a different set of options for how people are going to survive here over the next 10, 20, 30 years. It's going to have to look different if the predictions of the climatologists are accurate." Participants expressed concern that without such policy action, increasing heat risk education and warning messaging could become counterproductive, possibly discouraging and resulting in the disengagement of those individuals, families, and communities that can do little to respond.

4. Discussion

Despite the shared perception that heat risk education and warning messaging are lacking, interventions exist in San Diego County. For example, NWS San Diego disseminates heat risk information over its partner network and to the public via social media by issuing spatially explicit heat warnings/advisories. Additionally, county and local government agency websites address several of the knowledge gaps identified by participants (section 3), including causes of heat-related illness, populations at risk, symptoms and recommended protective actions, how to help others, and where and how to access cooling centers using no-cost transportation (e.g., County of San Diego Health and Human Services Agency: Extreme Heat). Applying participant recommendations to the above and other interventions could help to increase their reach and effectiveness in heat-vulnerable communities. Here, we discuss how those recommendations align with evidence-based support for successful hazard risk communication as well as the increasing valorization of dialogic models of communication.

The recommendation from participants to increase the reach of heat risk education and warning messaging by diversifying communication channels to include organizations and individuals that represent, serve, and/or are part of heat-vulnerable communities supports a move toward dialogic models of communication [27,58–61]. As explained (section 3.1), these organizations and individuals have high levels of social capital and can facilitate interaction and dialogue between messengers and receivers through established information and communication programs. This is in addition to providing translational, cultural, and other important guidance. The programs that participants listed should not be considered exhaustive but include those that serve as conduits of general information (e.g., from neighborhood schools to parents and families) and for health outreach and engagement (e.g., from clinics and health workers to farmworker and migrant communities). There is evidence to support the success of both types of programs in increasing the reach of hazard risk communication in other locations [27,82,83]. For example, in South Australia, neighborhood schools that have integrated presentation and discussion of hazard risk information into the curriculum, and additionally shared it with families, are now a primary resource for immigrant and refugee communities [27]. In another example, in the Los Angeles metropolitan area, the UCLA Labor Occupation Safety and Health Program (LOSH) developed a peer-trainer course for community health workers on workplace heat risk [82]. The course was based on popular education principles and methodology (see Refs. [84,85]) and involved extensive interaction and dialogue to ensure that it was relevant to and built on local experience [82]. In total, 159 peer trainers representing 70 community organizations participated in the course and together provided heat risk education to thousands of potentially at-risk individuals [82].

However, reach alone should not be the metric by which the success of heat risk education and warning messaging is evaluated. The receipt of heat risk information does not guarantee that it is processed and acted upon (see also [17]). Hazard risk communication is likely to be most effective when it addresses what the audience considers important to know [86]. This requires messengers to become familiar with the values, needs, and interests of receivers, either directly (e.g., through the dialogic models described above) or

indirectly (e.g., through research and practice [42]). The recommendation from participants to include greater specificity and comprehensiveness of detail in hazard risk communication – about which populations and geographic areas may be most vulnerable (Fig. 1), potential health impacts to at-risk populations or in specific geographic areas, and appropriate actions for mitigating those impacts – offers insight into what they as an audience consider important to know. It also aligns with documented good practice in hazard risk communication and certain cognitive models of persuasion, like the elaboration-likelihood model [87,88]. For example, research has shown that the absence of population, geographic (or locational), and temporal specificity in hazard risk communication provides little incentive for potentially at-risk individuals to seek additional information and take preparatory or protective action [49,54,89,90]. Instead, those individuals are more likely to forego active information seeking and passively monitor the hazard until an impending threat arises [49]. Research has also shown that at-risk groups often do not recognize their own vulnerability and heed alerts [17,37], suggesting that interventions should be designed to help them understand and evaluate their own risk and mitigation needs [32,37]. These interventions, for example wherein knowledge of vulnerabilities and triggers increases among people with chronic illness, are associated with greater intention to adopt recommended behaviors [91]. Finally, research has also shown that it should not be assumed that an uninformed public will know what constitutes appropriate protective action [54], nor that an informed public will understand and take seriously the benefits of adopting protective action [17]. In addition to informing people that they are at risk, warning messages must tell people what to do and why [54].

The recommendation from participants to present heat risk education and warning messaging in multiple languages and formats (e.g., storytelling and short video; section 3.2) also aligns with documented good practice [12,13,92] and reflects understanding of the relationship between inequities in information access and inequities in health outcomes (see Refs. [93,94]). Furthermore, research has shown that even where there are no language or literacy barriers, people learn and remember more efficiently and effectively through the combined use of text and visuals (as opposed to text alone) [95,96]. Yet simply translating an intervention into multiple languages or presenting information in a particular format does guarantee that it will be meaningful [97]. Relatedly, participants recommended that warning messaging be culturally competent, meaning that it be informed by understanding of the social and cultural influences that act on receiver beliefs and behaviors, to enhance uptake. It should also be informed by and seek to clarify or dispel cultural misconceptions and myths (see Refs. [97,98]). Cultural competence is a key element in hazard risk and other communication where social, cultural, and linguistic differences may exist between messengers and receivers [99,100]. It can also be key to developing trust where receivers are misapprehensive toward (particularly government) messengers [99,100]. This is important, as research has shown that hazard risk communication received from untrusted sources may be dismissed [27]. The potential benefits of developing cultural competence in heat risk education and warning messaging therefore include both the reduction of information and health inequities and the development of trust and social cohesion between messengers and receiver audiences that may include otherwise marginalized groups. The incorporation of culturally competent organizations and individuals into existing heat risk communication channels as recommended by participants (section 3.1) may offer an expedient approach to achieving those benefits. To be sure, some participants suggested that it is a role that they (or their organizations) could help fill (section 3.1).

The final suggestion from participants was to integrate the above recommendations into a formally coordinated, ongoing heat risk education and warning messaging campaign in order to proactively prepare communities for heat risk (section 3.3). Increased heat risk education is often cited as critical to influencing behavior [9,10,14]. Some researchers advocate for campaigns to be repeated at the beginning of every summer or otherwise ongoing until the public adopts protective action as a matter of course [35,101]. Certainly, such campaigns exist, for example as one component within government heat adaptation plans [10], though whether they typically are evaluated is unclear. In one exception, Oakman et al. [101] evaluated the "Beat the Heat: don't forget your drink" mass communication campaign designed to educate the public about heat risk mitigation in the Riverina-Murray region of New South Wales (Australia). Brief information sessions and soundbites were delivered to the public through radio and television and in unpaid community newspaper announcements. In a phone survey of 328 respondents, Oakman et al. [101] found that 63% reported hearing or seeing heat warnings, 54% indicated that they had modified their behavior, and 25% even recalled the slogan ("Beat the Heat"). Of the 46% of respondents who indicated that they had not changed their behavior, 96% reported that it was because they already routinely took protective action. However, it is important to note that this campaign complemented established occupational health and safety and duty of care laws, and the opportunities for and abilities of the general public to take protective action were considered to pre-exist [101]. Where such laws, opportunities, and abilities do not already exist, they may present challenges to the effectiveness of such campaigns (see Ref. [82]). Nonetheless, the success of the "Beat the Heat" campaign using more traditional communication channels suggests that an enhanced campaign, involving key organizations and individuals as trusted messengers (section 3.1) and ensuring specification of content (section 3.2), may be quite promising.

Barriers to heat risk communication and mitigation are well documented, and their persistence as noted by participants (section 3.4) highlights the need for progress toward eliminating underlying social, economic, and political inequities [17,36]. Governments can employ a range of strategies for doing so, including implementation of policies to protect outdoor and indoor workers, development of programs to make indoor cooling and energy more physically and financially accessible, and commitment to thermally adapted development and land-use planning [28]. Where government action is lacking, popular education has been employed at times in an effort to facilitate the conditions (or capacity-building) for people who have historically lacked power to expand and apply their knowledge to reduce or eliminate inequities [85]. The UCLA LOSH Program took this approach in the peer-trainer course developed for community health workers on workplace heat [82] as have others to address climate and health education more generally [102,103]. Specifically, the LOSH Program included activities for trainees to build the confidence and skills needed to take individual and collective action [82]. This included opportunities for trainees to practice their skills and receive feedback and to complete action plans detailing the outreach and education activities they intended to implement [82]. However, evaluation is needed to determine whether and how these approaches are effective in supporting action for change.

5. Conclusion

We conducted focus groups with individuals who represent, serve, and/or are part of heat-vulnerable communities in San Diego County to elicit their recommendations for increasing the reach and effectiveness of heat risk education and warning messaging. Those recommendations include: (1) diversification of communication channels, (2) specification of content, and (3) development of formally coordinated campaigns. Focus group participants also emphasized the importance of firm policy action directed both toward overcoming barriers to heat risk communication/mitigation and toward creating a more thermally adapted built environment. This action is needed to increase climate equity and ensure that heat-vulnerable communities can apply the education and warning messaging received.

Recommendations from participants align with evidence-based support for successful hazard risk communication as well as the increasing valorization of dialogic models of communication. We suggest that the recommendations should be applied and evaluated specifically within the context of heat risk education and warning messaging. Additional research into the transferability of participant recommendations to other regions characterized by extreme heat will also be important as agencies charged with hazard risk communication may have limited resources for public engagement. Relatedly, research into what types of organizations may be best suited to apply the recommendations, and the human and financial resources required for doing so, will also be important.

In the meantime, the numerous, detailed recommendations from participants reflect the value and importance of involving heat-vulnerable communities in the planning and implementation of interventions meant specifically to support them in taking protective action. To be sure, involving heat-vulnerable communities in hazard risk communication will require the building of relationships and trust to enable critical interaction and dialogue to take place. It will also require an openness and ability (e.g., within institutional norms and guidelines) to modify current approaches to hazard risk communication. Researchers already working with messengers in hazard risk communication may be well-positioned to help facilitate these efforts, especially if they are also connected to key organizations and individuals working with vulnerable communities. Addressing the above research questions, creating opportunities for involvement, and building relationships and trust will all take time. However, they are all critically important as heat extremes and population exposure continue to increase, and so should not be overlooked.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Table A1
Summary of key recommendations from focus group participants

Key Recommendations	
Diversification of communication channels	Integrate existing networks of trusted, key organizations and individuals into hazard risk communication channels: e.g., community-based organizations, neighborhood schools, peer-trainers/health outreach and engagement specialists, community and religious leaders, and others
	Integrate heat risk education and warning messaging into established information and communication programs, facilitated by the above networks: e.g., neighborhood schools to parents/families, clinics/health workers to migrant communities
Specification of content	Use locally defined metrics to make clear which geographic areas or populations within those areas may be most vulnerable to heat risk and why (e.g., by providing data from socioeconomic and spatial analyses of heat burden)
	Communicate explicitly about potential health impacts (and symptoms) to at-risk populations and/or in specific geographic areas
	Provide clear recommendations for mitigating health impacts, including at individual, household, and community levels

(*continued on next page*)

Table A1 (*continued*)

Key Recommendations	
	Use audience-specific languages and formats (e.g., storytelling and short video) to ensure information equity
	Ensure that the information communicated is culturally competent (e.g., clarifies misconceptions and dispels myths) to enhance uptake
Development of formally coordinated campaigns	In winter/spring, create training opportunities for key organizations and individuals to become educated about heat risk and integrated into existing communication channels (see the above recommendation to "diversify communication channels")
	In spring/early summer, utilize the expanded communication channels to conduct health outreach and engagement with heat-vulnerable communities
	In summer, continue health outreach and engagement utilizing the expanded communication channels to remind vulnerable communities of the potential for heat risk and to alert them to extreme heat throughout the warm season

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