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Review article

The driving influences of human perception to extreme heat: A scoping review

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ABSTRACT

Prior research demonstrates a link between heat risk perception and population response to a heat warning. Communicating a precise and understandable definition of "heat" or "heatwaves" can affect how a population perceives and responds to extreme heat. Still, little is known about how heat perception affects behavior changes to heat and heat communication across diverse populations. This scoping review aims to identify and describe the main themes and findings of recent heat perception research globally and map critical research gaps and priorities for future studies. Results revealed risk perception influences a person's exposure to and behavioral response to excessive heat. Risk perception varied geographically along the rural-urban continuum and was typically higher among vulnerable subgroups, including populations who were low-income, minority, and in poor health. A more integrated approach to refining risk communication strategies that result in a behavioral change and incorporates the individual, social, and cultural components of impactful group-based or community-wide interventions is needed. Research employing longitudinal or quasi-experimental designs and advanced statistical techniques are required to tease apart the independent and interacting factors that causally influence risk communication, heat perception, and adaptive behaviors. We advance a framework to conceptualize the structural, environmental, personal, and social drivers of population heat risk perception and how they interact to influence heat perception and adaptive behaviors. Our findings map future research priorities needed for heat perception and a framework to drive future research design.

1. Introduction

Exposure to extreme heat varies by geography and across a population. Human-induced changes to the earth exasperate extreme heat and increases exposure for those living nearby. These alterations often include the removal of vegetation, increase in impervious surfaces, and increases in anthropogenic heat from air conditioners and cars (Oke, 1982). Urban populations are known to be more exposed to extreme heat than rural populations because of the urban heat island effect (Zhang et al., 2020). Those who work outdoors or in warm environments are also more exposed (Sugg et al., 2018; Uejio et al., 2018). Additionally, those who do not have the means to take adaptive measures because of lack of access, lack of knowledge, and increased costs are often more at risk for exposure (Blum et al., 1998; Mason et al., 2017).

Excessive heat can cause significant health problems. Exposure to excessive heat, especially over an extended period, can cause heat exhaustion, heat stroke, dehydration, and death, along with more minor symptoms such as headache, nausea, sweating, and weakness (Luber and McGeehin, 2008). Those who have a reduced ability to thermoregulate (e.g., children and elderly), those who work outside or in a warm environment (Runkle et al., 2019), and those who do not take adaptive measures are more at risk for heat-related health issues (Fuhrmann et al., 2016; Luber and McGeehin, 2008).

Extreme heat, heatwaves, and excessive temperatures do not have a universal or formal definition. Often, heatwaves are defined based on health-based metrics, temperatures and/or humidity over a specific threshold, percentiles of average conditions, and/or these variables occurring over a certain amount of time (Robinson, 2000; Tong et al., 2015; Xu et al., 2016). A general definition that has been put forth by Perkins-Kirkpatrick and Lewis (2020) is "prolonged periods of excessive heat." However, acclimatization to high temperatures and humidity varies across climate types, so extreme heat in one location might be

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considered normal summer conditions in another location (Robinson, 2000). A person's acclimatization, lifestyle, history, adaptation and protective measures available, local interventions, and other variables can affect how they interact with and experience heat (Bakhsh et al., 2018; Mayrhuber et al., 2018; Robinson, 2000), thus biasing their perception if there is not a clear and consistent definition. Communicating a precise and understandable definition of "heat" or "heatwaves" can affect how a population perceives and understands their extreme heat risk.

Risk perception can affect a person's understanding of the risk of excessive heat and whether protective measures are used to reduce exposure. Early studies by Kalkstein and Sheridan (2007) and Sheridan (2007) suggest that communication of heat warnings results in greater risk perception, though the effectiveness of various protective measures is often still misunderstood or unknown. Common-sense protective measures, such as avoiding going outside during the warmest part of the day, are less effective at reducing exposure but commonplace, especially among vulnerable persons, such as the elderly and lower-income households who cannot afford air conditioning (Abrahamson et al., 2008; Sheridan, 2007). These early studies on heat perception are often limited to cross-sectional surveys and interviews, restricting the applicability of their results over diverse populations, geographies, and time periods (Abrahamson et al., 2008; Kalkstein and Sheridan, 2007; Semenza et al., 2008; Sheridan, 2007). More research employing a repeated measures design is needed to capture changes in heat risk perception and corresponding behavioral change throughout the warm season. Advantages to this less time- and cost-intensive design include enhanced statistical power, recruitment of a smaller number of research participants, and measurement of time-related effects (e.g., acclimatization, varying degrees of heat exposure) (Ellis, 1999; Verma, 2015).

This scoping review examines heat perception research published between 2010 and 2020 to 1) synthesize the main themes and findings of recent heat perception research; 2) determine the prominent study designs used in this field; 3) develop a framework to integrate the prominent factors that affect heat risk perception; and 4) identify heat perception research gaps and future research priorities. This study reveals that risk perception influences a person's exposure to and behavioral response to excessive heat and varies geographically. Perception is often higher among vulnerable subgroups, such as those in poor health. Our findings were conceptualized into a framework model describing the interactions between structural, environmental, personal, and social drivers of heat risk perception. We recommend that risk communication strategies are integrated within individual, social, and cultural components of each society. Future research should employ longitudinal or quasi-experimental designs to tease apart further independent and interacting factors that affect heat risk perception.

2. Methods

2.1. Databases, search terms, and inclusion/exclusion criteria

In June 2020, a systematic search was conducted in 2 electronic bibliographic databases, Web of Science and PubMed, to identify relevant peer-reviewed studies following the Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocols (PRISMA) guidelines for scoping review (Moher et al., 2009). Search terms included the following, "Heatwave" [Title/Abstract])) AND ("Perceptions" [Title/Abstract]) or "Heatwave" [Title/Abstract])) AND ("Perception" [Title/Abstract]) and applied to articles published from 2010 to 2020. This resulted in a total of 224 articles. Inclusion criteria included peer-reviewed articles that included heat perception as the main objective. Exclusion criteria comprised of conference abstracts, non-English, and that explicitly addressed heat perceptions as a secondary goal, such as perceptions on how climate and climate-change affect heat.

2.2. Data extraction

A total of 31 eligible articles were included in the final scoping review. Articles were extracted using the following criteria: First Author, Article Title, Year Published, Geographic Scale, Location, Study Population, Number of People Studied, Sampling Procedures, Study Design, Analysis, Time Period of Data Collection, Description of Heatwaves, Other Variables Considered, Key Findings and Study Limitations. Data abstraction was conducted using a standardized excel spreadsheet developed and pilot-tested by all authors on a sample of two papers. The authors discussed variables in this process, and extraction was finalized during multiple author meetings, where all authors reached a consensus.

2.3. Data synthesis

The scoping review articles were compiled into a single excel spreadsheet by all authors from July 2020 to August 2020. Descriptive statistics were used to delineate the number of articles published per year between 2010 and 2020 and the location the studies were conducted. Descriptive statistics and figures, including the frequency of articles and keywords, were performed in R using the packages *wordcloud* and *ggplot2* (Fellows, 2018; R Core Team, 2019; Wickman et al., 2019). Thematic analysis was performed on the following data extraction criteria: research gaps, key findings, description of heatwaves, and study limitations. For each criterion, articles were categorized into primary and secondary themes. Some articles contained multiple themes and were categorized into more than one primary and/or secondary theme. These analyses were used to develop a framework to illustrate the drivers of extreme heat perception and identify research gaps and directions for future heat perception research.

3. Results

3.1. Descriptive statistics

Of the 31 studies selected for the scoping review, most occurred in the latter half of the study period, with the maximum number of publications in 2013 ($n = 9$), 2017 ($n = 7$), and 2019 ($n = 7$) (Table 1). We attribute this surge in heat perception-related research interest to the 2010 heatwaves that affected much of the northern hemisphere, especially Asia, Europe, and Canada (NOAA, 2010). The geographic distribution of the studies was predominately in countries like the United States ($n = 9$), China ($n = 7$), and Australia ($n = 5$) (Fig. 1). Most studies analyzed collected data in an urban setting (67.7%, $n = 21$) or both urban and rural settings (25.8%, $n = 8$).

When comparing the selected articles' key findings, we found the following common words: health, perception, risk, adaptation, behaviors, effects, income, and urban (Fig. 2). Most studies reviewed ($n = 24$, 80%) use cross-sectional designs. Eight cross-sectional analyses employed advanced multi-level or mixed effect modeling. This type of

Table 1
The number of articles published each year from 2010 to 2020.

Year of Publication	Studies (%)
2010	1 (3.2)
2011	–
2012	1 (3.2)
2013	9 (29.0)
2014	1 (3.2)
2015	–
2016	1 (3.2)
2017	7 (22.6)
2018	3 (9.7)
2019	7 (22.6)
2020	1 (3.2)

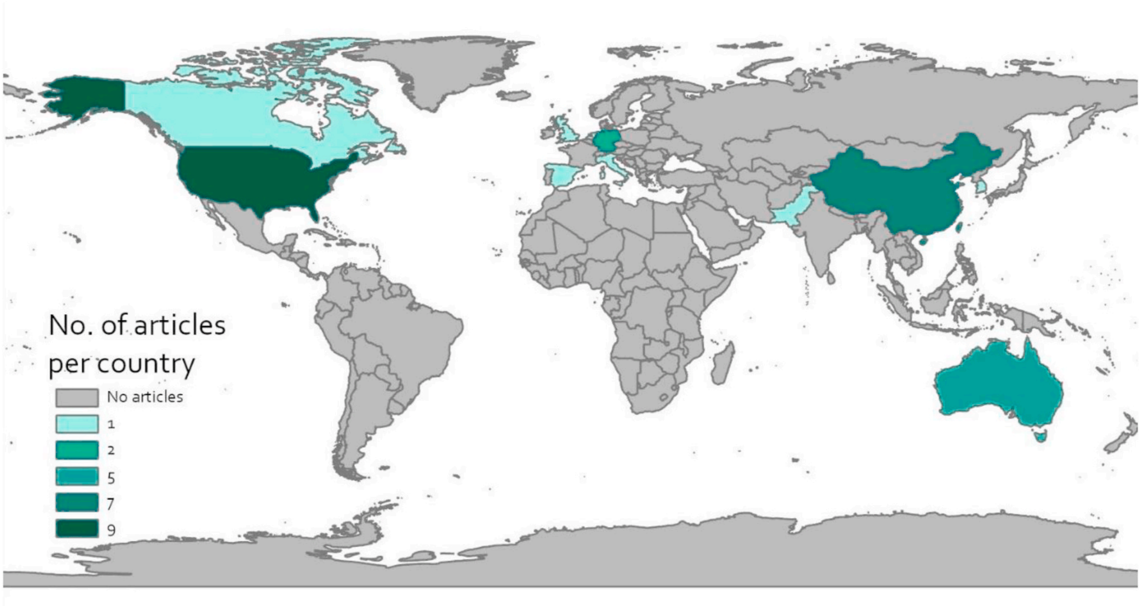

Fig. 1. Geographic distribution of study locations of heat perception articles in the scoping review.

Fig. 2. Word cloud of the key findings of all articles (excluded words: heat, heatwave).

modeling uses sophisticated statistical techniques to disentangle the complicated relationship between risk factors and risk perception. Seven studies were represented by qualitative research designs, followed by two longitudinal studies measuring the change in perception over time. Two cross-sectional studies and one longitudinal study used a mixed-methods approach. They included quantitative measures of indoor or outdoor conditions to validate self-reported heat exposure and perception.

3.2. Defining heat

Many studies ($n = 12$) reviewed did not address how the researchers defined heat or only referred to generic terms, such as high temperatures, extremely hot weather, or high heat. For studies that explicitly defined heat, three primary methods emerged. Five studies (Akompab et al., 2013a; Cutler et al., 2018; Hass and Ellis, 2019a; Lane et al., 2014; Zhou et al., 2014) used heat warning criteria or definitions provided by a local or federal meteorology office. Quasi-specific meteorological variables, such as warm temperatures that last for more than one day, were used to define heat and heatwaves in four studies (Gómez-Martín et al., 2014; Howe et al., 2019; Singh et al., 2015; Williams et al., 2019). Most often ($n = 10$), specific meteorological variables were used to define heat and heatwaves. Three studies (Ban et al., 2017; Esplin et al., 2019; Gómez-Martín et al., 2014) defined heat using upper percentiles of local conditions from historical climate data. Seven studies (Akompab et al., 2013a; Bai et al., 2013; Hass and Ellis, 2019a; Huang et al., 2018; Messeri et al., 2019; Quinn and Shaman, 2017) used either direct measurements of the environment and/or conditions above a set threshold that persisted for a specific duration. Hass and Ellis (2019b) specifically asked participants of a heat perception survey how they described hot weather. Responses defined hot weather by particular meteorological conditions (e.g., above 90 °F), whether they needed to change normal behaviors or activities, whether they felt discomfort, or whether they had health effects (Hass and Ellis, 2019b).

3.3. Drivers of extreme heat perception

Current research identifies four major domains that drive variance in extreme heat perception: structural, environmental, personal, and social (Fig. 3). Common structural drivers' themes included communication and warning systems ($n = 6$ studies), barriers to adaption ($n = 5$), and resource availability ($n = 5$). Common themes important to environmental drivers included meteorology or climatology ($n = 6$) and climate change ($n = 3$). Personal drivers had the common themes of adaptive and protective measures ($n = 19$) and health ($n = 14$). Finally, social drivers include common themes of sociodemographics ($n = 13$) and social support ($n = 9$). The major results from these studies are described below.

3.3.1. Environmental drivers

Several studies focused on how direct measurements of meteorological variables relate to heat perception. In general, high humidity will increase the perception of how warm a person is (Hass and Ellis, 2019a; Quinn and Shaman, 2017). This perception is especially important when understanding indoor heat exposure. When a person feels the indoor conditions are warmer, they perceive more heat-related health concerns (Quinn and Shaman, 2017). Perception will become more of a concern as our earth's climate continues to warm. Several studies identified the public's concern of a higher risk for heat exposure (Cutler et al., 2018; Matmir et al., 2017; Zander et al., 2017) and higher heat-related health risk (Akompab et al., 2013a; Bai et al., 2013; Ban et al., 2017) with a changing climate.

Geography influenced heat perception, though it affected individuals differently. Those living in a warm climate may express apathy and perceived acclimatization because they are exposed to excessive heat more often than in cooler locations (Hass and Ellis, 2019b; Howe et al., 2019). Both of these factors can lower the risk perception of heat. Those living in urban areas often considered themselves more vulnerable and have a higher risk perception (Howe et al., 2019).

3.3.2. Social drivers

Vulnerability to heat exposure and the associated health risks are related to social factors; age; income; and living conditions, such as building type, how many individuals within a household, homelessness, and urbanization levels (Bai et al., 2013; Liu et al., 2013; Reischl et al., 2018; Vu et al., 2019). Vulnerable populations, however, do not always have a high heat perception. For instance, older persons often have less perceived heat risk despite a reduced ability to thermoregulate, which

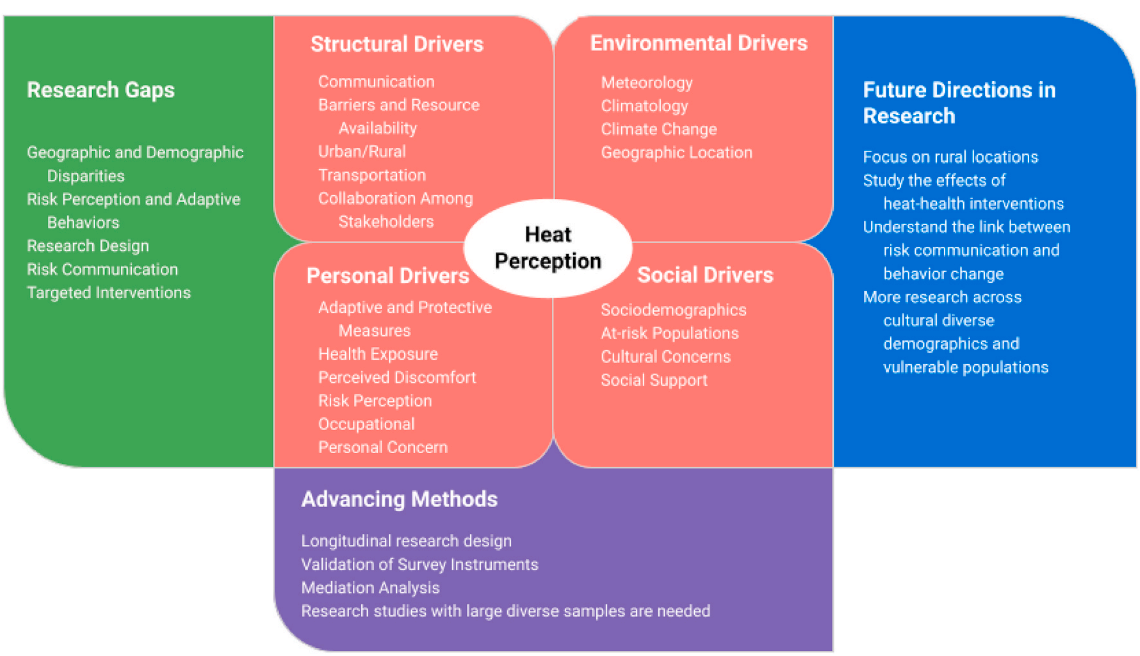

Fig. 3. Framework of common structural, environmental, personal, and social drivers studied in heat perception research; research gaps; future gaps in research; and options for advancing methods.

can result in less use of coping behaviors (Bittner and Stößel, 2012; Howe et al., 2019; Lane et al., 2014; Liu et al., 2013; Williams et al., 2019). Younger individuals often have more knowledge of risk for exposure (Williams et al., 2019), which is likely related to education access. Women typically express high heat risk perception as they often take on a larger caretaking role (Akompab et al., 2013a; Howe et al., 2019; Liu et al., 2013; Rauf et al., 2017; Williams et al., 2019). The gender bias of women having a higher risk perception is not always the case though. In some locations, such as China, men express a higher risk perception, often because of occupation (Beckmann and Hiete, 2020; Huang et al., 2018; Ye et al., 2018). In general, those who have more education are more likely to have high-risk perceptions of heat (Ban et al., 2017; Liu et al., 2013; Rauf et al., 2017). While those who are educated understand risk, those with a high income do not consider themselves at risk for exposure to heat or negative health outcomes, likely because they have more access to adaptive resources (Akompab et al., 2013b; Cutler et al., 2018; Rauf et al., 2017; Williams et al., 2019). Socially vulnerable and minority groups often perceive themselves at a higher risk of heat exposure as they often have less access to protective resources and often reside in areas with high urban heat island intensity (Cutler et al., 2018; Li et al., 2019; Rauf et al., 2017; Ye et al., 2018). Vu et al. (2019) suggest that federal policies that increase social support can reduce health inequality related to heat.

An individual's social structures and cohesion can influence their heat risk perception. For instance, living with others can increase risk perception when an individual is concerned about someone they live with (Akompab et al., 2013a). More commonly, though, living alone results in a higher risk for exposure and higher risk perception (Beckmann and Hiete, 2020; Hass and Ellis, 2019a; Sampson et al., 2018; Vu et al., 2019; Ye et al., 2018). Those who are married and/or have strong social cohesion are more likely to check on others in their neighborhood and family (Esplin et al., 2019; Rauf et al., 2017) and employ more adaptive behaviors, such as using air conditioning and seeking cooling centers (Sampson et al., 2018).

3.3.3. Personal drivers

Occupation can affect heat exposure and heat-related illnesses. Generally, working outdoors or in labor sectors places individuals at risk for more heat exposure (Hass and Ellis, 2019b; Li et al., 2019; Liu et al., 2013; Messeri et al., 2019; Singh et al., 2015; Zander et al., 2017; Zhou et al., 2014). There are several barriers to reducing heat exposure in the workplace. Workers typically have less autonomy to make protective changes to their work environment to reduce heat exposure and therefore are at a higher risk for negative health outcomes (Singh et al., 2015). Workers might feel "powerlessness" (Singh et al., 2015) because heat safety is often not seen as a priority and they have concerns about losing pay if productivity is reduced. There is often little accessibility to cool locations and fluids (Messeri et al., 2019; Zhou et al., 2014). Reducing heat exposure in migrant workers is often complicated by differences in language, safety training, and culture, potentially resulting in more heat exposure (Messeri et al., 2019).

Many research participants expressed concern for heat-related health risks (Akompab et al., 2013a; Ban et al., 2019). Those with a higher risk perception (Hass and Ellis, 2019b; Ye et al., 2018), in poor health (Bai et al., 2013; Ban et al., 2017; Beckmann and Hiete, 2020; Hass and Ellis, 2019b; Li et al., 2019; Williams et al., 2019; Ye et al., 2018; Zander et al., 2017), and ethnic minority groups (Li et al., 2019) have more concern about heat-related illnesses. Even though this is likely related to vulnerability, a lack of resources, and previous experiences, those who have a better understanding of heat and the related health risks because of more education, higher income, and more access to healthcare are also concerned about heat health (Ban et al., 2017; Cutler et al., 2018; Rauf et al., 2017). While physical health concerns, such as dehydration and heat exhaustion, are commonly cited, the effects of extreme heat on mental health as it relates to anxiety and worry are becoming more prevalent in the literature (Akompab et al., 2013a; Hass and Ellis, 2019b; Sampson et al., 2018).

Adaptive and protective behaviors can reduce heat exposure and are often facilitated by heat risk perception (Ban et al., 2019). Air conditioning was the most prominently cited adaptive measure in the research (Ban et al., 2017; Hass and Ellis, 2019b; Li et al., 2019; Matmir et al., 2017; Sampson et al., 2018; Williams et al., 2019; Zhou et al., 2014). Despite its widespread use, cost and income can be barriers to access or use of air conditioning (Bai et al., 2013; Hass and Ellis, 2019b; Huang et al., 2018; Liu et al., 2013; Matmir et al., 2017; Sampson et al., 2018; Valois et al., 2017). Other adaptive measures are often employed in addition to or instead of air conditioning. Staying hydrated, avoiding the mid-day sun or peak heat exposure, seeking a cooling center or cooler location, staying inside, and using fans were also cited as preferred adaption methods (Bai et al., 2013; Bittner and Stößel, 2012; Hass and Ellis, 2019b; Lane et al., 2014; Li et al., 2019; Liu et al., 2013; Sampson et al., 2018; Williams et al., 2019).

While adaptive measures are used across all socio-demographic groups (Esplin et al., 2019), whether protective behaviors are employed is primarily based on personal and structural (further discussed in section 3.3.4) factors. In general, younger and more educated individuals tend to use more adaptive behaviors (Hass and Ellis, 2019a; Williams et al., 2019). Likewise, when someone has previously experienced heat and heat health effects or knows someone who has, they are more likely to engage in adaptive behaviors (Akompab et al., 2013a; Ban et al., 2017; Esplin et al., 2019; Hass and Ellis, 2019b; Rauf et al., 2017; Sampson et al., 2018; Zander et al., 2017). However, when a person believes they are acclimatized to heat or believe they already know what measures to take, they are less likely to take protective measures (Hass and Ellis, 2019b; Lane et al., 2014; Williams et al., 2019).

3.3.4. Structural drivers

Structural adaptations at the city level, such as green spaces, less impervious surfaces, and increasing the number of trees, can reduce exposure to ambient heat. However, decision-makers often consider heat mitigation a lower priority than other climate hazards, such as floods (Reischl et al., 2018; Van Loenhout et al., 2016). In some areas, such as the Netherlands and Belgium, city- or country-wide heatwave plans are viewed favorably by the public (Van Loenhout et al., 2016) whereas in other locations, such as the United Kingdom, citizens do not feel they are at risk and do not see the benefits of heatwave plans (Wolf et al., 2010). Heatwave warnings and plans would benefit from incorporating public education interventions to increase the publics' use of protective measures (Vu et al., 2019).

Heatwave warnings are often used to warn that extreme heat is imminent and that those in the affected area should take precautions. Adaptive measures are more often taken when it is widely known that there is a heatwave (Hass and Ellis, 2019a). Warnings are primarily received via the tv, radio, and newspaper (Akompab et al., 2013a; Bittner and Stößel, 2012; Kim et al., 2014; Rauf et al., 2017). The internet (Rauf et al., 2017) and healthcare worker communication (Bittner and Stößel, 2012) are also standard communication methods. However, many people, specifically those with less education, are older, or are lower income, are less likely to receive heat warnings, which may result in less protective measures being employed (Kim et al., 2014; Lane et al., 2014; Ye et al., 2018).

4. Discussion

This study is one of the first to examine recent evidence-based literature on heat perception globally. We examined a comprehensive volume of literature published between 2010 and 2020 and analyzed the key concepts. Results were synthesized into a conceptual framework for future research at the intersection of heat perception and the associated social, personal, environmental, and structural drivers. From this, we determined the current research gaps in heat perception research. These include geographic and demographic disparities in data collection, a broader understanding of risk perception's influence on adaptive behaviors, advancing heat risk communication, options for policy-level targeted interventions, and opportunities for more comprehensive research designs and methods.

4.1. Research gaps

The health and societal impacts of excessive heat affect all societies. This scoping review revealed that heat perception research is being conducted worldwide, particularly in developed countries like Australia, China, and the United States. Yet, we noted several critical research gaps and priorities for future studies, which are discussed further below.

4.1.1. Geographic and demographic disparities

Rural locations and other underrepresented locations, such as developing countries, require further investigation as rural heat perception and behavior response may vary compared to urban counterparts. Our scoping review found the greatest concentration of research articles in developed countries (e.g., United States, Australia). Researchers concentrated on urban locations within these countries, with only two articles focusing solely on rural locations (Messeri et al., 2019; Williams et al., 2019). Geographic disparities among rural and urban areas can be further identified by incorporating place-based factors (e.g., racial segregation, crime rates, road density) and identifying underlying disparities (e.g., poverty, employment status) that drive local heat risk perception and the behavior/adaptive response. For example, several cities in the United States show warmer land surface temperatures in areas where more low-income and minority persons reside. This is likely a result of redlining, the discriminatory practice of denying services and loans based on the racial and ethnic composition of neighborhoods (Hoffman et al., 2020; Wilson, 2020).

In addition to the greater diversity of the study locations, more representative samples or larger sample sizes are needed to understand heat perception among sub-populations (Ban et al., 2017; Quinn and Shaman, 2017; Zhou et al., 2014). Multiple articles highlight the need for additional research of vulnerable populations (i.e., unhoused, socially isolated) and unique demographics, such as ethnic minorities, childcare providers, or decision-makers (Bai et al., 2013; Bittner and Stößel, 2012; Li et al., 2019; Matmir et al., 2017; Van Loenhout et al., 2016; Ye et al., 2018). We recommend that future research includes rural locations, larger geographic areas with varying degrees of rurality, and large representative samples for various sub-populations.

4.1.2. Risk perception and adaptive behaviors

Several studies noted the need for understanding the broader community, policy, cultural (Bai et al., 2013; Ye et al., 2018), environmental, and political (Cutler et al., 2018) influences on heat perception and associated adaptive behaviors (Ban et al., 2017; Williams et al., 2019; Wolf et al., 2010; Zander et al., 2017). Understanding these broader contexts can result in successful top-down approaches, such as policy interventions or heat warning systems, that promote adaptive behaviors (Kim et al., 2014; Williams et al., 2019).

Through heat warnings, risk communication can leverage an individual's heat perception to encourage adaptive behaviors that decrease heat exposure (Akompab et al., 2013a; Hass and Ellis, 2019b; Huang et al., 2018; Kim et al., 2014; Lane et al., 2014; Liu et al., 2013; Sampson et al., 2018). Linking of heat perception with adaptive behaviors is essential for effective public health interventions (Ban et al., 2019; Beckmann and Hiete, 2020; Gómez-Martín et al., 2014; Hass and Ellis, 2019a, 2019b; Kim et al., 2014; Matmir et al., 2017; Valois et al., 2017; Wolf et al., 2010). In contrast, other studies recommend reinforcing protective behaviors among adults who already take adaptive actions rather than promoting protective behaviors in diverse populations where the factors that influence activity are unclear (Williams et al., 2019). This lack of consensus in the research highlights a need to understand the causality link between heat perceptions and adaptive behaviors across diverse populations.

4.1.3. Advancing risk communication

The advancement of heat risk communication requires a better understanding of heat warnings to more closely align heat perception with ambient conditions (Akompab et al., 2013b; Hass and Ellis, 2019b; Huang et al., 2018; Kim et al., 2014; Lane et al., 2014; Liu et al., 2013; Sampson et al., 2018). Messaging needs to be intergenerational as older generations may need assistance from younger generations who are often caregivers (Sampson et al., 2018). Although researchers explicitly state the need for refining risk communication (e.g., Akompab et al., 2013b; Hass and Ellis, 2019a), no reviewed studies directly examined appropriate messaging based on heat perception as in earlier studies (e.g., Kalkstein and Sheridan, 2007; Sheridan, 2007). Research is needed on populations where risk communication does not promote adaptive behaviors to better understand how heat perception can spark protective measures among resistant individuals. Lastly, risk communication strategies and heat prevention strategies must be studied using rigorous research designs, like quasi-experimental research designs, to ensure they promote healthy change and reduce heat exposure among the larger population (Beckmann and Hiete, 2020; Bittner and Stößel, 2012; Esplin et al., 2019; Singh et al., 2015).

4.1.4. Targeted interventions

Results of our review reveal that few studies have been conducted with individual, community, or policy-level intervention as an end goal. Additionally, while the current evidence base has captured individual-level perceptions of extreme heat, few studies have captured the effectiveness of applying these research findings to community-wide interventions or the increased use of protective measures in targeted groups (e.g., occupational, vulnerable minorities). For example, research has demonstrated that high heat risk perception was not sufficient to motivate willingness toward employing adaptive behaviors that protect against heat-health concerns in occupational (Singh et al., 2015) and ethnic minority groups (Li et al., 2019).

Ultimately, more research that engages with people in power, like public health leaders and employers who can advance systemic changes in the workplace, is needed to achieve collective and sustained protective action and effective policies. One example in which individuals and decision-makers come together is demonstrated by Zhou et al. (2014). The study investigated the understanding of extreme heat's physiologic and psychological effects amongst city bus drivers and their managers. Barriers to heat adaption among drivers included equitable workplace policies to reduce heat within the context of budget constraints and more extensive community-level interventions like road greening (Zhou et al., 2014). An urban and peri-urban study examined individual- and household-level characteristics that influence heat risk perception, promote heat adaption, and connect these characteristics with policy implications and communication campaigns in Pakistan (Rauf et al., 2017), which is reinforced by recent urban and peri-urban work in Pakistan (Bakhsh et al., 2018).

We recommend future research that examines the role of community education in promoting sustained usage of protective behaviors and developing and testing integrated communication and heat prevention programs that prioritize the most vulnerable needs in a community, state, or region. This work should pair targeted interventions with public health intervention assessments to advance quantitative metrics that measure population resilience to excessive heat over time.

4.1.5. Research methods to advance the science

The research to date has been focused on cross-sectional survey design among limited subpopulations. Cross-sectional designs only capture a snapshot of an individual's heat exposure or risk perception. No causal associations can be inferred between individual characteristics and risk perception. This can impede the field's advancement and understanding of the key drivers of heat risk perception.

Rigorous research methods and advancements are needed to improve causal understanding of heat perception and how it may spark adaptive behaviors. First, self-reported heat exposure and heat perception risk are subject to recall bias. Future studies should incorporate quantitative measures of heat stress or heat exposure. These advances are needed to validate survey measurements to compare self-reported heat perception with quantitative measures of heat exposure among diverse groups. Research in wearable sensors (e.g., Hass and Ellis, 2019a; Kuras et al., 2015) and GPS technology (e.g., Runkle et al., 2019; Sugg et al., 2019, 2018) can provide a quantitative measurement of how adaptive behaviors affect exposure and can validate survey responses. Second, emerging statistical methods, such as mediation analysis, are required to tease apart the complex independent and interacting factors that influence risk communication, heat perception, and adaptive behaviors. These methodologies must be paired with robust research designs to enhance inquiry on the causal linkages between these factors and underlying individual characteristics and border community contexts and are considered important next steps in environmental exposure research (Schmidt et al., 2018). Enhanced study designs include longitudinal assessments, quasi-experimental, and, when possible, community randomized controlled trials (Schmidt et al., 2018). Third, large sample sizes are required across a diverse range of individuals and geographic locations to disentangle the effects of local climate and place-based factors (e.g., urban, rural) on geographic disparities in heat risk exposure and risk perception.

4.1.6. Emerging themes

The majority of studies have focused on retrospective or near-term extreme heat events, revealing a gap in the current evidence-base on examining future heatwaves (Howe et al., 2019; Matmir et al., 2017), especially among socially vulnerable individuals. A recent study relying on scenario building and fuzzy mapping investigated the concerns and perceived impact of climate on urban residents in New York City (Matmir et al., 2017). Findings showed that low-income city residents were far more concerned about the effects of heat than their wealthier counterparts. Another study sought to model perceived risk using local census-derived socio-economic data and determined that perceived risks were highest in urban centers, Southern states, and among some African Americans and Hispanic/Latino populations (Howe et al., 2019). More research examining the critical social and cultural components of impactful interventions are needed to move citizens from apathetic to engaged and closer towards heat-protective behaviors.

4.2. Limitations

This study is limited in scope as we focused on articles that were published between 2010 and 2020. We did not include articles that addressed heat perception as a secondary or tertiary goal (e.g., perception of the effect of climate change on heat). We also excluded articles in the grey literature and those that are not available in English. Relevant articles related to our objectives may also have been missed by our search criteria, thus influencing our results and findings.

5. Conclusions

This study is one of the first to examine recent evidence-based research on heat perception from literature published between 2010 and 2020. Our findings highlight the drivers of extreme heat risk perception, which include environmental, social, personal, and structural factors. Future research on heat risk perception should include examination of rural areas, studies with larger and more representative samples from vulnerable subgroups, the types of effective risk communication strategies that promote adaptive behavior, and the application of more rigorous research designs (e.g., quasi-experimental). Given that high heat risk perception is a motivating factor for good adaptive behavior during periods of extreme heat, more cross-disciplinary research is needed to identify culturally appropriate and innovative ways to improve population-level heat perception. Addressing these research gaps will be a critical next step in ensuring the health and well-being of all members of society in the context of an increasingly warm planet.

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Declaration of competing interest

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