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ORIGINAL ARTICLE

Individual heat adaptation: Analyzing risk communication, warnings, heat risk perception, and protective behavior in three German cities

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Abstract
Extreme heat poses severe health threats, as the increased numbers of hospitalizations and fatalities during heat waves show, though little is known about adaptive behavior toward heat. We conducted a household survey on individual perceptions of heat stress and individual heat protection in the summer and autumn of 2019. In total, 1417 people from three medium-sized German cities participated via telephone or online. Based on the Protective Action Decision Model (PADM), which we adapted to heat stress, we analyzed links between risk perception, environmental and demographic factors, perceptions of stakeholders, different heat warning messages, as well as actual and intended adaptive behavior. Overall, the PADM constructs explained around 16% of the variance in protection motivation, 19% in protective response, and 23% in emotion-focused coping. Context factors (i.e., temperature, risk communication, gender, age, and homeownership) were significant predictors of the addressed outcome variables as were psychological factors (i.e., perceived personal vulnerability, response efficacy, response costs, preparedness, and perceived external responsibility). We further explored the effect of different warning messages on situational knowledge and intended behavioral adaptation in an experimental setting. Results showed that respondents felt significantly better informed after receiving a warning with action recommendations and reported more intended specific behaviors. Our research gives insights into individual protective action decision-making processes. Based on our findings, we recommend tailoring risk communication strategies and combining heat warnings with action recommendations whenever possible to increase understanding and individual adaptation.

KEYWORDS
heat stress, natural hazards, Protective Action Decision Model, protective behavior, vulnerability

1 | INTRODUCTION

Over the last decades, we have witnessed an increase in weather extremes globally (IPCC, 2012; WMO, 2019). In particular, there is a rise in annual average temperatures as well as longer and more intense heat waves worldwide with record-breaking temperatures (Coumou & Rahmstorf, 2012; CRED, 2021) which threatens human health and life: research shows an increase in mortality and hospitalization numbers during heat waves (an der Heiden et al., 2019; Karlsson & Ziebarth, 2018; Li et al., 2015; Robine et al., 2008). Heat stress is a serious health threat for vulnerable groups, such as the elderly, children, and people with pre-existing medical conditions, who thus need to be the focus of heat risk management (Lissner et al., 2012; Mees et al., 2015; Schuster et al., 2017; WHO, 2021). The urban heat island effect explains the phenomenon that urban areas are more strongly affected by heat stress than their rural surroundings, and this effect increases the larger and more densely populated a city becomes (Zhou et al., 2017). In Germany more than one third of the inhabitants live in urban areas (Otto, Göpfert et al., 2021; Otto, Kern, et al., 2021) and are therefore more exposed to heat as was shown by Gabriel and Endlicher (2011) for the city of Berlin and rural parts of Brandenburg.

This study is set in Germany where the topic of heat waves is of urgent relevance, too. The global trend of increased annual average temperatures and more extreme heat waves also applies to Europe and Germany (Dalelane & Deutschländer, 2013; Fischer & Schär, 2010; Jacob et al., 2014), provoking growing numbers of citizens experiencing negative health impacts, thus higher costs for the health system and ultimately an increase in fatalities (Forzieri et al., 2017). In Germany, the years from 2018 to 2020 were the hottest years on record to date (DWD, 2020) and almost 20,000 heat-related fatalities occurred during these three summers (Winklmayr et al., 2022).

Individual adaptation and protective action can mitigate or prevent many harmful consequences of heat stress as well as reduce the number of fatalities (Shooshtarian et al., 2018; WHO, 2011, 2021). With this article, we aim to explain pathways to individual heat adaptation and explore components of an experimental heat warning. The key outcome variables we explored are *protective action decision making* (later: protection motivation), which indicates an intention to act; *protective response*, which indicates the extent to which specific actions are implemented or planned, and *emotion-focused coping*, consisting of aspects such as fatalism and denial. This theory-driven approach was carried out with a telephone (CATI, computer-aided telephone interviews) and web-based (CAWI, computer-aided web interviews) survey in an urban sample covering different climatic conditions in Germany.

1.1 | Heat risk communication and individual adaptation

The awareness of the risks of heat stress is often lacking as many studies have pointed out (Abrahamson et al., 2009; Bittner & Stößel, 2012; Howe et al., 2019; Wolf et al., 2010). A recent review on heat risk perception summarizes factors that are positively associated with risk perception, such as belonging to low-income groups or minorities, or having a poor health status (Hass et al., 2021). Since risk perception is a predictor of adaptation to heat (Esplin et al., 2019; van Valkengoed & Steg, 2019) efforts are made to foster it. In this context, risk communication in general and heat warnings in particular are crucial elements of heat risk management: the aim of communication approaches is to increase people's risk perception and eventually motivate them to perform protection behavior.

In Europe, a number of heat-health warning systems (HHWSs) are in place that substantially differ in the number of alert levels, their thresholds, and color codes among others, as Casanueva et al. (2019) showed. The authors compared HHWSs from 16 European countries. Warning thresholds are based on, for example, epidemiological, biometeorological, climatological, and practical considerations. In Germany, the benchmark for an official heat warning (level 1: strong heat stress) is an expected Perceived Temperature (PT) of ≥32°C and only little cooling at night (DWD, 2022b). PT is the thermal index used by the meteorological service DWD (see de Freitas & Grigorieva, 2017 for a comparison of human thermal climate indices). In general, warning thresholds can differ regionally, take acclimatization into account, and are based on epidemiological research and knowledge on thermophysiological strain (Casanueva et al., 2019; Matzarakis et al., 2020). According to a representative population survey by Capellaro et al. (2015), heat warnings are known by the 71% of German citizens. However, there is not much known about individual responses to such warnings.

Research shows that HHWSs can help reduce heat-induced mortalities (Chiabai et al., 2018; Toloo et al., 2013). Germany experiences increasing efforts to implement heat adaptation strategies: in 2020, 19 regional heat health action plans were recorded (Blättner et al., 2020). One study from the German city of Frankfurt (Main) showed that the installation of a heat-health action plan and a heat warning system was resulted in a decrease in excess mortality (Heudorf & Schade, 2014). Research from the United Kingdom and France suggests that national heat-health action plans can have an impact on individual adaptation and protective behavior (Khare et al., 2015; Pascal et al., 2021). However, not much is known on which aspects of a warning affect adaptive behavior; therefore thorough evaluation is needed.

Often the link between communication, perception, and behavior is not as clear as expected by risk managers. Existing studies on the interdependence of risk perception and adaptation show heterogeneous results, as Hass et al. (2021) find. Other factors next to risk communication can play a role in either fostering or hampering risk perception and protection behavior. For a better understanding, behavioral theories serve as helpful research frameworks.

1.2 | Theoretical framework: The Protective Action Decision Model (PADM)

A number of behavioral theories and models exist to explain human behavior in risk contexts. Most of them are rooted in social or health psychology, but many have been adapted and successfully applied to environmental psychology and disaster risk research (Heidenreich, Köhler, et al., 2020; Kuhlicke et al., 2020). Among all natural hazards, most research is conducted on flooding and some on wildfire and hurricanes, but there is a particular lack of theory-driven research on heat risk behavior (van Valkengoed & Steg, 2019).

To date, the Protection Motivation Theory (PMT; Rogers, 1975, 1983) is the most widely used theory to explain adaptive and/or protective behavior in the field of natural

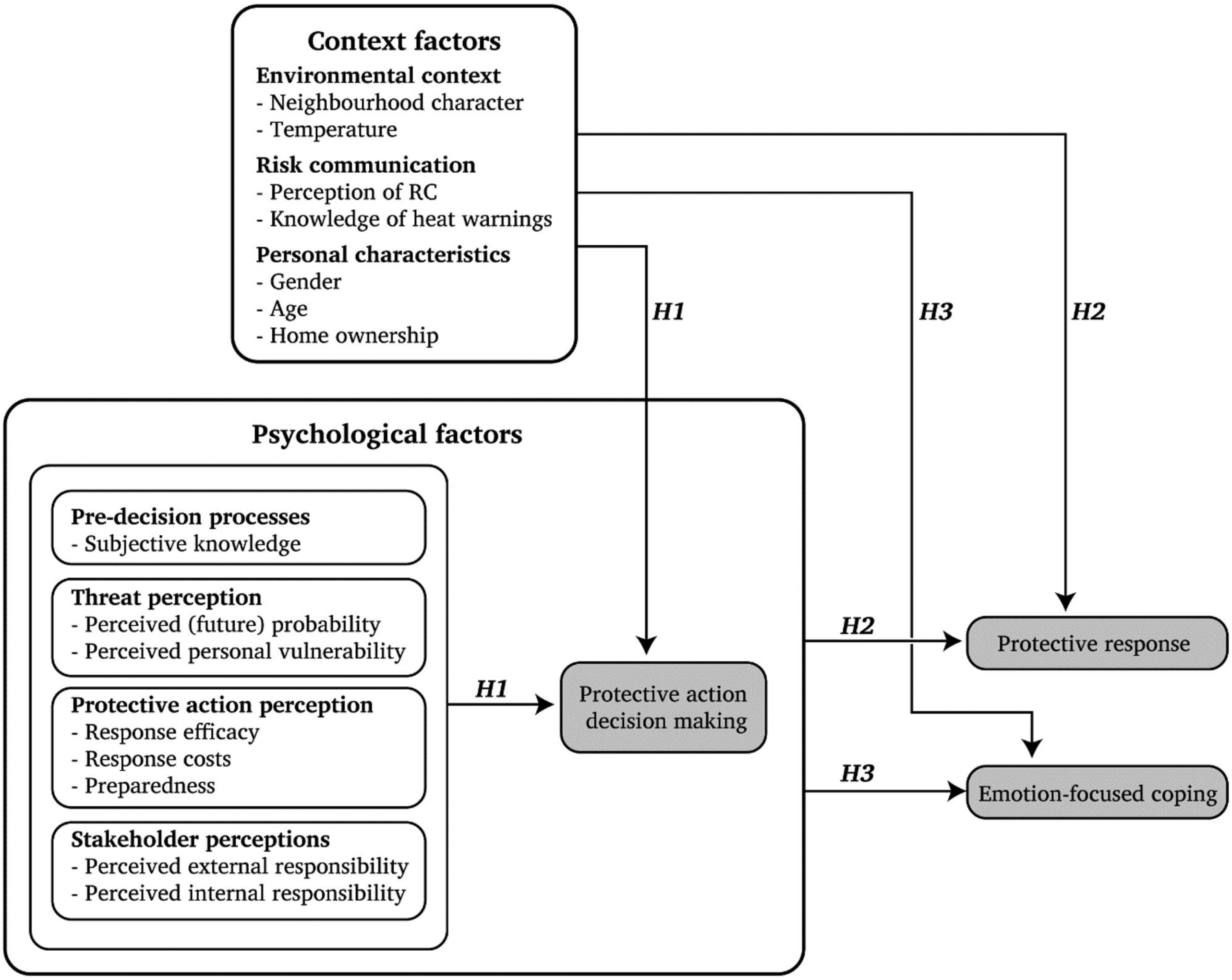

FIGURE 1 Hypotheses 1, 2, and 3 based on the Protective Action Decision Model (PADM). Outcome variables are marked in gray.

hazards, such as flooding (Bamberg et al., 2017; Grothmann & Reusswig, 2006; Heidenreich, Masson et al., 2020; Seebauer & Babcicky, 2021). Budhathoki et al. (2020) applied the PMT to both heat and flooding in a sample of Nepalese farmers and extended the theory to explain motivation to adapt to weather extremes. According to the PMT, threat appraisal and coping appraisal predict protection motivation and consequently behavioral responses including potential maladaptive behavior which includes emotional strategies such as denial and fatalism.

The PADM (Lindell & Perry, 2012) includes constructs comparable to those of the PMT, but adds further components such as stakeholder perceptions. With regard to pluvial flooding, the perception of own responsibility and responsibility of stakeholders was found to be important to explain (maladaptive) behavior (Dillenardt et al., 2022; Hudson et al., 2022). Moreover, the PADM sets a focus on aspects of the social and environmental context and personal characteristics. The theory describes the psychological factors (see Figure 1) of predecision processes, perceptions of threat, protective action and stakeholders, and protective action decision making (synonym for protection motivation in PMT). The behavioral response is given as a result of both the contextual and psychological factors. This behavior can be on the one hand a protective (or adaptive) response, which can involve carrying out measures to protect oneself from the respective risk, such as drinking more water, changing one's working hours, or installing sun protection shields in one's home in the case of heat. On the other hand, the behavioral response can take the form of emotion-focused coping, which is sometimes described as maladaptive coping and may manifest in such phenomena as fatalism, denial, or wishful thinking, among others. So far, PADM has been successfully applied to a number of natural hazards, such as flooding (Terpstra & Lindell, 2012) and wildfire (Strahan & Watson, 2019). In a recent study on household-level heat adaptation, Beckmann et al. (2021) surveyed 431 citizens from Augsburg/Germany and asked them to collect data with a temperature logger in their apartment during the summer of 2019. The authors found influences of general self-efficacy, heat risk perception, age, indoor temperature, subjective heat stress, and health implications on adaptive behavior. Still, the PADM is under-researched in the context of heat stress and we aimed at operationalizing the theory's constructs with a stronger focus on heat.

1.3 | Focus of this research

Research on how heat risk perception and communication relate to heat adaptive behavior is scarce (van Valkengoed & Steg, 2019) and there is a call in the literature for studies on (quasi) experimental research interventions with large, heterogeneous samples to improve the understanding on heat risk behavior (Hass et al., 2021). We addressed these research gaps by conceptualizing a theory-driven approach based on the PADM. In accordance with this theoretical framework, we explored which environmental, social, and psychological factors are positively associated with aspects of behavioral responses. The PADM has been applied to develop risk communication programs and explain adaptation to (natural) hazards (Lindell & Perry, 2012). The theory contains contextual factors, such as the environmental context, risk communication, and personal characteristics, as well as elements of psychological processes/factors (see above) which can predict protective action decision making and behavior. Throughout the hazard literature, the terms protection and adaptation behavior are often used interchangeably. Since the PADM focuses on protection/protective behavior we use this wording in our article. Self-reported heat perception and exposure may be biased and quantitative measures of exposure are requested (Hass et al., 2021). Therefore, we added per case the official mean air temperature determined at the respondents' place of residence on the day of the survey. Regarding the behavioral aspect, emotion-focused coping and a protective response can be differentiated. We aim at explaining protective action decision making, protective response, and emotion-focused coping concerning heat stress by analyzing explanatory factors described in the PADM. Building on past research on the PADM in different hazard fields (e.g., Beckmann et al., 2021; Heath et al., 2018; Lindell & Perry, 2012; Strahan & Watson, 2019; Terpstra & Lindell, 2012) we propose the following three explorative hypotheses (Figure 1):

H1 Psychological factors considerably improve predictions of protective action decision making in addition to contextual factors.

H2 Psychological factors considerably improve predictions of protective response in addition to contextual factors.

Research on hazard-related behavior only seldom addresses aspects of emotion-focused, maladaptive, or negative coping (Babcicky & Seebauer, 2019; Heidenreich, Köhler, et al., 2020). Following the PADM structure, we specifically address this behavioral aspect (Figure 1):

H3 Psychological factors considerably improve predictions of emotion-focused coping in addition to contextual factors.

The hypotheses are investigated based on a household survey. Within the survey, an experimental heat warning was included. By manipulating the warning message (as part of PADM's context factor of *risk communication*), we explored impacts on perceived situational knowledge on protective actions (psychological factor of *predecision processes* in the PADM) as well as their adaptation intentions (psychological factor of *protective action decision making* in the PADM). Research from the context of flooding revealed that people who received warnings with helpful information knew better what to do to protect themselves (Kreibich et al., 2021; Kuller et al., 2021). We thus propose two further hypotheses (Figure 2):

H4 A heat warning with action recommendations increases the receivers' situational knowledge on protective action as well as their adaptation intentions, compared to a heat warning without action recommendations.

As stated above, heat increases hospitalization and mortality numbers. This negative impact on human health may increase with the growing duration of hot temperatures which is called the heat wave effect (Hajat et al., 2006; Li et al., 2015). We assume that people intuitively experience the effect heat has on them even stronger if their body has no time to recover from hot temperatures over a longer time. To the best of our knowledge, there is no literature on the relationship of severe heat events on peoples' situational knowledge on adaptation. Thus, we openly explore this possible connection:

H5 A warning for a longer heat event has an impact on the receivers' perceived situational knowledge on protective action.

Finally, we expect a warning on 3 days of heat which may be called a heat wave to result in higher awareness and eventually behavioral intentions (Figure 2):

H6 A warning for a longer heat event evokes higher levels of adaptation intentions, compared to a warning for a shorter heat event.

2 | METHODS AND DATA

The survey was carried out between August 19 and October 19, 2019 in three German cities: Potsdam (in the federal state of Brandenburg), Remscheid (North Rhine-Westphalia), and Würzburg (Bavaria). Both conceptual as well as practical considerations (existing project partnerships with the cities) influenced our choice of settings. These cities were chosen as representatives for the large population in German cities.

FIGURE 2 Hypotheses 4, 5, and 6 on the heat warning experiment.

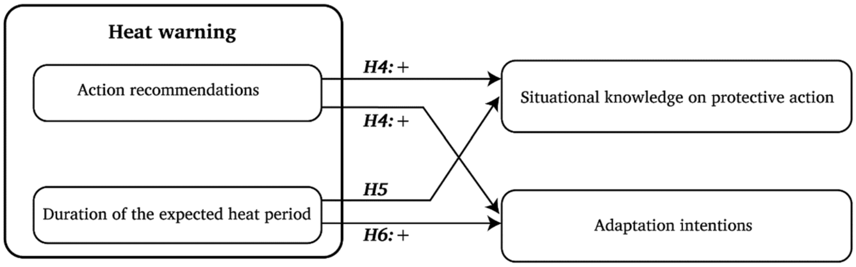

Figure 3 shows the location of the three cities. The cities' populations range from 111,000 to 181,000 inhabitants, with Remscheid being the smallest of the three, but the most densely populated (Destatis, 2021b). These medium-sized cities are located in different German regions and represent different climate area types. According to the Federal Environment Agency (UBA, 2015), Potsdam and Würzburg are located in drier climate areas, whereas Remscheid is situated in a low mountain climate. In the near future, however, all three cities will likely experience a shift to a warmer climate (UBA, 2015).

Using CORINE Land Cover data from 2018 (Bundesamt für Kartographie und Geodäsie [BKG], 2020), we calculated the cities' proportion of green, blue, and gray (i.e., sealed) areas. Potsdam had the largest proportions of both green and blue areas compared to Remscheid and Würzburg (Figure 3). For further analyzes, we segmented the municipal areas based on postal codes in order to define the participants' neighborhood character. The average daily temperature during the survey period (August 19, 2019 to October 19, 2019) in the surveyed areas was taken from the German Meteorological Service (DWD Climate Data Center, 2021). Of the three cities, Potsdam had the highest average and maximum day temperatures (see Figure 3). Comparing past heat warnings (DWD, 2022a) in the three cities since the DWD launched the German HHWS in 2005, we see the highest average number of annual heat waves in Würzburg (Figure 3).

2.1 | Sample

In order to address different age groups, the survey was carried out in two different formats: via telephone (CATI, random sampling) and online (CAWI, advertisements in the news as well as by posters and leaflets in the cities). The response rate of the telephone survey in the three cities was between 6% and 8%, due to sample-neutral (e.g., wrong number, no answer; 25–27 %) and systematic dropouts

		Potsdam	Remscheid	Würzburg
Height above sea level		32 m	365 m	177 m
Area (in km²)		188.24	74.52	87.60
Proportion of area characteristics	green	65%	59%	58%
	blue	9%	1%	1%
	grey	25%	40%	40%
Population		180 334	111 338	127.934
Population density (per km²)		958	1 494	1 460
Average day temperature during survey period		17.5°C	14.7°C	17.3°C
Maximum day temperature during survey period		34.1°C	32.9°C	33.4°C
Average temperature (1981 – 2010)		9.3 °C	8.8 °C	9.6 °C
Warmest month		July: 19.0 °C	July: 17.1 °C	July: 19.2 °C
Average number of heat warning per year (2005-2019)		10.1 (5.2)	8.1 (4.4)	13.3 (5.2)

FIGURE 3 Location of survey settings with geographic and demographic information on the survey cities.

Note. Information on area, height, and population are taken from Destatis (2021b). Proportion of area characteristics are our own calculations with 2018 CORINE Land Cover data from the German Federal Agency for Cartography and Geodesy (BKG, 2020). Temperature data are taken from DWD Climate Data Center (2021) for DWD station id 3987 (Potsdam), 4154 (Remscheid), and 5705 (Würzburg). Number of heat warnings per year is taken from DWD (2022a) and reported in the format: mean (standard deviation).

TABLE 1 Personal characteristics per city and survey mode (CATI/CAWI).

			Gender (%)			Age (years)	
		N	f	m	d	*M*	*SD*
Total sample	CATI	900	59.1	40.9	0.0	64.75	16.16
	CAWI	517	55.3	44.5	0.2	45.13	15.72
	Total	1417	57.7	42.2	0.1	57.81	18.55
Potsdam	CATI	320	62.8	37.2	0.0	68.02	14.39
	CAWI	155	64.5	34.8	0.6	43.00	14.87
	Total	475	63.4	36.4	0.2	60.11	18.62
Remscheid	CATI	278	58.3	41.7	0.0	64.34	16.00
	CAWI	79	36.7	63.3	0.0	57.13	12.77
	Total	357	53.2	46.5	0.0	62.83	15.64
Würzburg	CATI	302	56.0	44.0	0.0	61.67	17.43
	CAWI	283	55.5	44.5	0.0	43.04	15.49
	Total	585	55.7	44.3	0.0	52.87	18.97

Abbreviations: CATI, computer-aided telephone interviews; CAWI, computer-aided web interviews; f, female; m, male; d, diverse.

(e.g., refused participation; 67−72 %). The interviews lasted on average about 27 min online (CAWI), and 35 min via telephone (CATI).

All in all, 1417 people participated in the survey, of which 900 were collected by CATI and 517 by CAWI, as can be seen in Table 1. In total, 585 people from Würzburg, 475 people from Potsdam, and 357 people from Remscheid participated in the study. The respondents were on average 57.8 years old (CATI: 64.8; CAWI: 45.1) and 57.7% were female (CATI: 59.1%; CAWI: 55.3%). Compared to the German population statistics that report for December 31, 2019 a proportion of 50.7% women and a mean age of 44.5 years (Destatis, 2021a), our sample is on average older than the general German population and women are overrepresented.

The average subjective health status of the respondents was "good" ($M = 2.70$; $SD = 0.87$; on a scale from 1 = "excellent" to 5 = "bad"). Most of the respondents were tenants (54.1%), some were homeowners (31.8%), and the smallest group of respondents owned the apartment they lived in (12.1%). In Potsdam, the group of tenants was substantially higher (67.5%) compared to Remscheid (36.9%). Due to a high nonresponse rate (35.6%) for income, we excluded this item from further analyzes.

2.2 | Data and questionnaire design

The questionnaire contained 52 questions in total. Based on the PADM framework (Figure 1), items from the questionnaire and further data were used for the following analyzes. In Table 2, all relevant constructs and their corresponding items are listed together with their corresponding answer scales and Cronbach's alpha.

Environmental Context. The neighborhood character is described by the proportions of green, blue, and gray areas of the participants' postal code areas that were calculated as explained above. The mean temperature of the survey day was obtained from the DWD Climate Data Center (2021).

Risk Communication. Participants were asked about their *perception of their city administration's risk communication* and whether they had been *aware of heat warnings* in the current or past year (i.e., in 2018 and 2019, which had both exceptionally warm summers including some heat waves). The *personal characteristics* of age and gender as well as homeownership were included.

In PADM's central section (see Figure 1) labeled *psychological factors*, first the *predecision processes* were addressed. We assessed the participants' *subjective knowledge on heat adaptation*. Different subaspects of *threat perceptions* were measured with items on *perceived future probability* and *personal vulnerability*. To capture *protective action perception*, we included questions on *perceived response efficacy*, *response costs*, and *preparedness*. We further focused on one aspect of *stakeholder perceptions* and asked the participants who they thought was responsible for implementing adaptations and protections to heat stress in three different everyday settings (at home, at work, in the neighborhood). We aggregated a set of items to retrieve both a level of perceived *external responsibility* (i.e., other stakeholders the participants thought should be responsible), and perceived *internal responsibility* (i.e., the participants expressed self-responsibility in the aforementioned settings).

The participants' level of *protective action decision making* was assessed by a question on *protection motivation*. Furthermore, we measured two types of outcome *behavior*. On the one hand, *emotion-focused coping* was recorded with a four-item scale that covered aspects of fatalism, denial, wishful thinking, and postponement (see Table 2). On the other hand, *protective response* was explored through self-reported past behavior concerning private building precaution.

TABLE 2 Constructs and items with answer options.

Factor	Question/Explanation	Answer scale	*N*	*α*
Environmental context				
Temperature	Mean temperature on the survey day in the participant's city (Figure 3)	Temperature in °C	1417	–
Neighborhood character	The share of gray (sealed), green, or blue areas in the direct neighborhood of the respondent (own calculations based on postal codes and CORINE data (Figure 3)	in %	1308	–
Risk communication				
Perception of risk communication	Our city informs us very well about heat risks and possible adaptation measures.	1 = "I fully agree" – 6 = "I don't agree at all"[a]	1266	–
Knowledge of heat warnings	Were you aware of any heat warnings for your hometown in the current or last year?	1 = yes; 0 = no	1417	–
Personal characteristics				
Gender female	Which gender are you?	1 = female, 0 = male	1416	
Age	How old are you?	In full years, no decimals	1329	
Homeownership	Are you renting or do you own the house or apartment you live in?	0 = I rent. 1 = I own the house or apartment I live in.	1389	
Predecision processes				
Subjective knowledge	How well do you feel informed about heat adaptation in general?	1 = not informed at all; 6 = very well informed	1417	–
Threat perceptions				
Perceived (Future) probability	In future years, there will be more and more heat waves in my hometown.	1 = "I fully agree" – 6 = "I don't agree at all"[a]	1341	–
Perceived personal vulnerability	I am susceptible to heat stress.		1413	
Protective action perception				
Perceived response-efficacy	Individual adaptation measures can reduce negative impacts of heat stress significantly.	1 = "I fully agree" – 6 = "I don't agree at all"[a]	1332	–
Perceived response costs	Individual adaptation is too expensive.		1228	
Preparedness	I am well prepared for a coming heat wave.		1357	
Stakeholder perceptions				
Perceived external responsibility	In your opinion, who is responsible for preventing negative impacts of heat stress for you in the following contexts? Contexts: (a) at home, (b) at work, (c) in my neighborhood Stakeholders: (a) my family or other people I live with; the house owner, (b) my employer; (c) the municipal authorities; the health sector (hospitals, rescue services, doctors, and pharmacies); transport companies; care and educational institutions (child care facilities and schools); private companies (gastronomy, retail)	1 = not responsible at all 6 = very strongly responsible For further analysis, a scale mean of all eight items was calculated	1379	0.84
Perceived internal responsibility	(see perceived external responsibility): answer option "myself" in each of the three contexts	See perceived external responsibility	1385	0.55

(Continues)

TABLE 2 (Continued)

Factor	Question/Explanation	Answer scale	N	α
Protective action decision making				
Protection motivation	I will do anything in my power to protect myself and my family from heat stress.	1 = "I fully agree" – 6 = "I don't agree at all"[a]	1369	–
Emotion-focused coping				
Fatalism	There is nothing one can do against heat stress and the damages it causes.	1 = "I fully agree" – 6 = "I don't agree at all"[a]	1410	0.53
Denial	I try not to think much about how I could be affected negatively by heat waves.			
Wishful thinking	It will not get as unbearably hot as it was in the summers of 2018 and 2019.			
Postponement	Heat is just one problem among many and simply not a priority in my life.			
Protective response				
Building precaution	There are building precaution measures that can help mitigate heat stress. Please indicate which of the following measures you have implemented, planned, do not intend to implement, and which are not possible:[b] 1. Automated night ventilation 2. Installation of an air conditioning system 3. Green roofs/ facades 4. Construction of water areas and wells 5. Unsealing and greening of places and other open spaces 6. Thermal insulation glazing or window protection films 7. Installation of fans 8. Facade and roof insulation 9. Greening the inner courtyard, garden, front garden 10. Sun protection devices; darkening	1 = implemented 2 = planned 3 = not intended 4 = not possible *Note*: For further analyzes, the answers were transformed to 1 = "implemented/planned" and 0 = "not intended/not possible" and the sum of positive answers was calculated, resulting in a possible value range of 0–10 for each case	1417	.60

[a]These items were recoded for the correlation and regression analyzes, high item values indicating higher levels in the respective construct.
[b]The list of measures was presented in randomized order.

2.3 | Heat warning experiment

Within the last third of the questionnaire, we presented a warning message to the survey participants. Within the PADM framework, warnings are part of risk communication and belong to the contextual factors. The warning messages were randomly assigned to one out of four groups and received the respective warning, which differed in two factors. The warning was about either 1 day of heat (Version 1) or 3 days of heat (Version 2, see factor "duration" in Table 3), and was followed by either no further information (Version A) or specific action recommendations on adequate behavioral responses (Version B, see factor "action recommendation" in Table 3). In total, 364 people received the warning combination Version 1A (meaning a warning for 1 day of heat with no action recommendations), 320 received Version 1B, 355 received 2A, and 373 received 2B. Five cases were excluded because more than one warning message was presented due to technical mistakes in the survey software.

After the warning, two questions were presented (see Table 3). Respondents were asked about their perceived situational knowledge on protective action which means how well they knew what to do after receiving the warning (the question was inspired by the item "knowledge of how to protect oneself" by Kreibich et al., 2021). This aspect represents the first step of PADM's psychological factors: *predecision processes*. Furthermore, a list of 22 specific adaptation measures was presented and the respondents were asked to indicate which of them they would intend to implement after having received the warning (see Table 3). These behavioral intentions are part of *protective action decision making*.

2.4 | Statistical analyzes

All statistical analyzes were conducted with IBM SPSS, Version 28. Descriptive analyzes were reported to present the sample characteristics. Correlation analyzes were performed

TABLE 3 The warning experiment: Warning text and following questions. The participants received a randomized warning message which differed in two factors (duration: Version 1 or 2; action recommendation: Version A or B) and subsequently answered two questions.

Warning message		
The German Weather Service publishes heat warnings in case of very high expected temperatures. This is a typical warning:		
Official warning of HEAT for your city.		
Duration	**Version 1** [1 day, $N = 684$] Valid from: tomorrow 10:30 a.m. until: tomorrow 7:00 p.m. **Version 2** [3 days, $N = 728$] Valid from: tomorrow 10:30 a.m. until: in 3 days 7:00 p.m.	
	Tomorrow an extreme heat load with felt temperatures of more than 35°C is expected.	
Action recommendation	**Version A** [no info, $N = 719$] **Version B** [info, $N = 693$] What can I do? During a heat wave you should follow these three basic rules: 1. Avoid the heat. 2. 2 Keep your home cool. 3. Keep your body cool and make sure that you have sufficient fluid and electrolyte supply. If you are caring for people who need help or care, make sure that these three basic rules are also observed by them. If you or others experience unusual health problems such as circulatory problems, headaches or vomiting, contact a doctor.	
Questions presented after the warning		
Factor	Question	Answer options
Situational knowledge on protective action	Based on this warning, do you know what to do to prevent negative impacts of heat stress?	1 = "I know absolutely what to do" – 6 = "I don't know what to do at all"
Adaptation intention $\alpha = 0.77$	After receiving such a warning, what would you do?[a] 1. Adapt ventilation (at night, cool) 2. Drink more (nonalcoholic, cool) 3. Stay in the shade 4. Avoid midday sun and heat 5. Use sun protection devices; darken rooms 6. Use thin bedsheets 7. Eat light, small meals 8. Avoid effort and physical stress 9. Move to cooler spaces 10. Switch off or reduce heat sources 11. Use sun protection for skin and eyes 12. Use air conditioning 13. Check body temperature 14. Change working hours 15. Use cooling care products 16. Hang up damp cloths 17. Go for a swim 18. Use a fan or hand fans 19. Pass on heat warning information to others 20. Take care of family members 21. Cool the body (e.g., shower, keep hair moist, etc.) 22. Wear light, loose clothing and head coverings	1 = yes 2 = no 3 = not possible *Note*: For further analyzes, the answers were transformed to 1 = "yes" and 0 = "no/not possible" and the sum of positive answers was calculated, resulting in a possible value range of 0–22 for each case

[a]The list of measures was presented in randomized order.

to test interdependencies and interconnections between variables of the PADM. Multiple linear regression analyzes were carried out to explain the effect of the PADM factors on *protective action decision making* and *behavior* (H1–H3, Figure 1). To facilitate the interpretation of correlation and regression results, the items marked in Table 2 were recoded such that higher item values consistently indicate higher levels in the respective construct, and vice versa. Analyzes were carried out for complete cases in the whole sample. In order to examine the effects of the heat warning on the participants' comprehension and total adaptation intentions (H4–H6, Figure 2), two-way ANOVAs were calculated. To check for effects on specific adaptation intention measures X^2 tests were calculated. All effect sizes were interpreted according to Cohen (1988).

3 | RESULTS

3.1 | Descriptive and correlative results

Table 4 shows the descriptive results for all items belonging to the PADM constructs for the whole sample and the three cities' subsamples separately. The participants expressed on average a rather negative perception of their cities' risk communication (M = 4.14, SD = 1.66). Heat warnings were familiar to the majority (84%) and most participants perceived their subjective knowledge about heat adaptation as good (M = 3.96, SD = 1.34). The *probability of future heat waves* occurring in their hometowns was perceived as high (M = 1.77, SD = 1.15), whereas their *perceived personal vulnerability* was closer to the scale's midpoint (M = 2.95, SD = 1.80). *Response efficacy* was perceived as rather high (M = 2.23, SD = 1.37), whereas *perceived response costs* (M = 3.01, SD = 1.69) and *preparedness* (M = 3.04, SD = 1.50) ranged closer to the scales' midpoints. All mentioned stakeholders were considered to be highly responsible. A t-test revealed that the composite level of *perceived external responsibility* (M = 4.63, SD = 1.13) was significantly higher than the *perceived internal responsibility* (M = 4.09, SD = 1.22), $t(1374) = 13.99$; $p < 0.001$. Most participants expressed on average a high level of *protection motivation* (M = 1.95, SD = 1.23). Regarding the *protective response*, we saw that on average 3.24 (SD = 1.87) out of 10 possible *building precaution measures* (see Table 2) were indicated as either implemented or planned. We observed a medium level of *emotion-focused coping* (M = 3.74, SD = 1.14). Taking a look at the sample's responses regarding *protective action decision making* and *behavior*, we observed some differences between the three cities with however merely small effect sizes (see Table 4). Therefore, we focus on the results for the whole sample below.

There were a number of small to medium correlations between various PADM constructs (Table 5). The participants' personal characteristics were connected to some of the psychological factors and behaviors: there were small positive correlations between female *gender* and *perceived personal vulnerability* (r = 0.18), *perceived response costs* (r = 0.10), and *protection motivation* (r = 0.11). Age showed small correlations with *preparedness* (r = 0.22), perceived *external responsibility* (r = −0.16), *internal responsibility* (r = 0.11), and *protection motivation* (r = 0.16). Furthermore, age was correlated with emotion-focused coping on a medium level (r = 0.31; Table 5).

Among the constructs belonging to the psychological factors (Figure 1), perceived response costs and preparedness stood out, showing a number of weak correlations with other constructs (Table 5). The constructs of protective action decision making and behavior showed weak correlations among each other: *protective response* was correlated positively with *protection motivation* (r = 0.12), and negatively with *emotion-focused coping* (r = −0.12).

Analyzing the respondents' general awareness of heat warnings, we see that most (84%) had received heat warnings in the current or past year (Table 4). Television (47.6%), radio (39.2%), apps (27.2%), Internet research (16.4%), and daily newspapers (15.9%) were most frequently mentioned as information sources of heat warnings. A number of respondents reported using storm-tracking weather apps (8.3%) or receiving the warning through other people (5.2%) or (online) social networks (5.0%). Less frequently mentioned warning sources (<5% each) were employers, doctors and pharmacies, respondents' own electronic weather stations, care facilities, and educational facilities.

3.2 | Impacts of PADM constructs on protection motivation and behavior

To explain *protection motivation* (representing *protective action decision making* based on the PADM, see H1), multiple linear regression analyzes were calculated. Model 1 (Table 6) included context factors (Figure 1). These items explained a small but significant share of the variance in protection motivation, $R^2 = 0.05$, F (9, 888) = 5.646, $p < 0.001$. The strongest predictors were *temperature* (negative), female *gender*, and *age*, meaning that higher temperature was rather associated with a decrease in protection motivation, and women as well people of higher age showed higher levels of protection motivation. After adding items of the PADM psychological factors (Model 2, Table 6), $\Delta R^2 = 0.11$, F (8, 880) = 14.113, $p < 0.001$ more variance was explained, supporting H1, $R^2 = 0.16$, F (17, 880) = 9.984, $p < 0.001$. *Temperature*, *age, and gender* remained significant predictors. Furthermore, perceived *personal vulnerability*, *perceived response efficacy*, *perceived response costs*, *preparedness*, and *perceived external responsibility* positively predicted *protection motivation* (Table 6).

The following regression (Model 1, Table 7) shows that context factors significantly explained a significant share of the *protective response*, for example, the number of implemented and planned building precaution measures, R^2 = 0.14, F (9, 888) = 15.387, $p < 0.001$. Out of the group of

TABLE 4 Means (*M*) and Standard Deviations (*SD*) for Protective Action Decision Model (PADM) factors of risk communication, psychological factors, and behavior.

	Total		Potsdam		Remscheid		Würzburg	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Perception of risk communication*	4.14	1.66	3.98	1.62	4.02	1.76	4.32	1.61
	1226		*396*		*308*		*522*	
Knowledge of heat warnings	0.84	0.37	0.88	0.32	0.82	0.38	0.84	0.38
	1417		*475*		*357*		*585*	
Subjective knowledge	3.96	1.34	3.94	1.34	4.04	1.42	3.94	1.30
	1417		*475*		*357*		*585*	
Perceived future probability	1.77	1.15	1.81	1.12	1.90	1.26	1.67	1.08
	1341		*451*		*355*		*555*	
Perceived personal vulnerability	2.95	1.80	2.93	1.81	3.15	1.89	2.84	1.72
	1413		*474*		*354*		*585*	
Response efficacy	2.23	1.37	2.19	1.35	2.15	1.42	2.31	1.36
	1332		*443*		*330*		*559*	
Perceived response costs	3.01	1.69	2.96	1.69	3.05	1.74	3.03	1.67
	1228		*406*		*302*		*520*	
Preparedness*	3.04	1.50	3.04	1.51	2.76	1.48	3.20	1.49
	1357		*455*		*331*		*571*	
Perceived external responsibility	4.63	1.13	4.55	1.20	4.63	1.20	4.69	1.03
	1379		*458*		*349*		*572*	
Perceived internal responsibility	4.09	1.22	4.06	1.30	4.22	1.25	4.02	1.14
	1385		*462*		*351*		*572*	
Protection motivation*[a]	1.95	1.23	1.80	1.10	2.01	1.43	2.05	1.19
	1369		*459*		*343*		*567*	
Emotion-focused coping*[b]	3.74	1.14	3.65	1.17	3.57	1.20	3.91	1.10
	1410		*471*		*354*		*585*	
Protective response	3.24	1.87	3.09	1.80	3.33	1.82	3.30	1.95
	1417		*475*		*357*		*585*	

Note. Below each *M* and *SD*, the corresponding *n* is displayed in italics. Sample means differed significantly between the cities according to one-way ANOVAs at * $p < 0.01$.
[a] F (2, 1366) = 5.945, $p = 0.003$, $\eta^2 = 0.009$.
[b] F (2, 1410) = 12.215, $p < 0.001$, $\eta^2 = 0.017$.

context factors, *homeownership* was a strong positive predictor, meaning that people who owned the apartment or house they lived in performed a higher number of protective responses. Knowing about heat warnings had a positive impact of marginal significance. Adding psychological factors including *protection motivation* to the regression, the share of explained variance rose by $\Delta R^2 = 0.05$, F (9, 879) = 6.275, $p < 0.001$ (Model 2), $R^2 = 0.19$, F (18, 879) = 11.242, $p < 0.001$. This supports H2. *Homeownership*, *gender*, as well as *perceived response costs* were identified as negative predictors, while *personal vulnerability*, *preparedness*, and *protection motivation* were positive predictors for *protective response* (Table 7).

Following the same procedure, two regression analyzes were calculated for emotion-focused coping exploring H3 (Table 8). Model 1 reveals that contextual factors significantly predicted the dependent variable, $R^2 = 0.14$, F (9, 809) = 14.907, $p < 0.001$. Temperature, knowledge of heat warnings, and homeownership negatively predicted emotion-focused coping, while the participants' perception of risk communication and their age, were positive predictors. By adding the psychological factors including protection motivation into the regression, the share of explained variance grew significantly by $\Delta R^2 = 0.09$, F (9, 800) = 10.671, $p < 0.001$ (Model 2, Table 8) to $R^2 = 0.23$, F (18, 800) = 13.591, $p < 0.001$. Next to the aforementioned significant context factors, perceived personal vulnerability and perceived external responsibility negatively predicted, whereas perceived response costs and preparedness, positively explained emotion-focused coping (Table 8). Thus, H3 was supported.

3.3 | Heat warning experiment

After having received the experimental warning message (see Table 3), the respondents reported a high level of situational

TABLE 5 Bivariate correlations between Protective Action Decision Model (PADM) constructs.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Day mean temperature																			
2	Gray area	−0.04																		
		1308																		
3	Green area	−0.03	−0.58*																	
		1308	*1308*																	
4	Blue area	0.11*	−0.29*	0.13*																
		1308	*1308*	*1308*																
5	Perception of risk comm.	−0.06$^+$	−0.06$^+$	0.06	0.02															
		1226	*1141*	*1141*	*1141*															
6	Knowledge of heat warnings	0.02	−0.02	−0.01	0.04	−0.03														
		1417	*1308*	*1308*	*1308*	*1226*														
7	Gender female	−0.00	−0.01	−0.01	0.06$^+$	0.08*	0.01													
		1416	*1307*	*1307*	*1307*	*1225*	*1416*													
8	Age	−0.14*	−0.03	0.03	0.02	0.21*	−0.13*	0.00												
		1329	*1249*	*1249*	*1249*	*1161*	*1329*	*1328*												
9	Homeownership	−0.07*	−0.08*	0.18*	−0.18*	0.05	−0.05	−0.10*	0.17*											
		1389	*1287*	*1287*	*1287*	*1206*	*1389*	*1388*	*1313*											
10	Subjective knowledge	−0.02	−0.00	0.05	−0.02	0.24*	0.05$^+$	0.02	0.08*	0.08*										
		1417	*1308*	*1308*	*1308*	*1226*	*1417*	*1416*	*1329*	*1389*										
11	Perceived future probability	0.01	0.05	−0.02	0.02	−0.06$^+$	0.08*	0.07*	−0.09*	−0.01	−0.01									
		1341	*1240*	*1240*	*1240*	*1178*	*1341*	*1340*	*1262*	*1316*	*1341*									

(Continues)

TABLE 5 (Continued)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
12	Perceived personal vulnerability	0.05	0.02	−0.03	.02	−0.09*	0.13*	0.18*	−0.09*	−0.09*	−0.10*	0.26*								
		1413	*1304*	*1304*	*1304*	*1223*	*1413*	*1412*	*1326*	*1385*	*1413*	*1338*								
13	Perceived response efficacy	0.05	0.05	−0.04	0.02	0.12*	−0.04	−0.02	0.08*	0.09*	0.09*	0.05	−0.04							
		1332	*1229*	*1229*	*1229*	*1174*	*1332*	*1331*	*1251*	*1308*	*1332*	*1270*	*1329*							
14	Perceived response costs	−0.00	0.03	−0.02	0.03	−0.04	0.01	0.10*	0.02	−0.13*	−0.11*	0.02	0.09*	−0.04						
		1228	*1135*	*1135*	*1135*	*1092*	*1228*	*1227*	*1157*	*1207*	*1228*	*1174*	*1225*	*1183*						
15	Preparedness	−0.07*	−0.02	0.08*	−0.02	.25*	−0.05	0.02	0.22*	0.20*	0.22*	−0.11*	−0.24*	0.26*	−0.06$^+$					
		1357	*1256*	*1256*	*1256*	*1189*	*1357*	*1356*	*1276*	*1334*	*1357*	*1290*	*1354*	*1296*	*1195*					
16	Perceived external responsibility	0.03	−0.02	0.04	0.02	−0.05	0.02	0.08*	−0.16*	0.00	0.09*	0.06$^+$	0.08*	0.06$^+$	0.01	0.01				
		1379	*1271*	*1271*	*1271*	*1199*	*1379*	*1378*	*1299*	*1357*	*1379*	*1311*	*1376*	*1308*	*1209*	*1332*				
17	Perceived internal responsibility	−0.00	−0.08*	0.08*	0.01	0.08*	0.01	0.00	0.11*	0.15*	0.19*	−0.00	−0.08*	0.09*	−0.12*	0.19*	0.25*			
		1385	*1277*	*1277*	*1277*	*1205*	*1385*	*1384*	*1305*	*1363*	*1385*	*1316*	*1382*	*1313*	*1214*	*1339*	*1375*			
18	Protection motivation	−0.07$^+$	−0.02	−0.01	0.04	0.06$^+$	0.02	0.10*	0.16*	0.02	0.04	0.13*	0.14*	0.24*	0.12*	0.17*	0.13*	0.07$^+$		
		1369	*1267*	*1267*	*1267*	*1202*	*1369*	*1368*	*1289*	*1347*	*1369*	*1298*	*1366*	*1308*	*1202*	*1325*	*1343*	*1350*		
19	Protective response	0.02	−0.08*	0.07$^+$	−0.08*	−0.00	0.08*	−0.09*	0.00	0.34*	0.03	0.06$^+$	0.04	0.14*	−0.14*	0.17*	0.05$^+$	0.13*	0.12*	
		1417	*1308*	*1308*	*1308*	*1226*	*1417*	*1416*	*1329*	*1389*	*1417*	*1341*	*1413*	*1332*	*1228*	*1357*	*1379*	*1385*	*1369*	
20	Emotion-focused coping	−0.14*	−0.01	0.05	0.01	0.21	−0.11*	0.00	0.31*	0.00	0.04	−0.21*	−0.13*	0.09*	0.18*	0.26*	−0.04	−0.03	0.09*	−0.12*
		1410	*1303*	*1303*	*1303*	*1226*	*1410*	*1409*	*1324*	*1383*	*1410*	*1336*	*1406*	*1332*	*1227*	*1357*	*1376*	*1382*	*1369*	*1410*

Note. Bivariate correlations are significant at $^+$ $p < 0.05$; $^*p < 0.01$. Below each correlation, the corresponding n is displayed in italics.

TABLE 6 Multiple linear regression testing the impact of context factors and psychological factors on protection motivation (as part of protective action decision making; Hypothesis 1, see Figure 1).

	Model 1			Model 2		
	B	SE(B)	β	B	SE(B)	β
Constant	4.51**	0.27		2.28**	0.35	
Daily mean temperature	−0.02+	0.01	−0.08	−0.02*	0.01	−0.08
Gray area	0.00	0.00	−0.02	0.00	0.00	−0.03
Green area	0.00	0.00	0.03	0.00	0.00	0.01
Blue area	0.01	0.01	0.04	0.01	0.01	0.03
Perception of risk communication	0.00	0.02	0.00	−0.01	0.02	−0.02
Knowledge of heat warnings	0.15	0.11	0.05	0.14	0.10	0.04
Female	0.25*	0.07	0.11	0.14+	0.07	0.06
Age	0.01**	0.00	0.16	0.01**	0.00	0.14
Homeownership	0.13	0.08	0.06	0.04	0.08	0.02
Subjective knowledge				0.00	0.03	0.00
Perceived future probability				0.00	0.00	0.02
Perceived personal vulnerability				0.09**	0.02	0.14
Perceived response efficacy				0.16**	0.03	0.19
Perceived response costs				0.06+	0.02	0.08
Preparedness				0.11**	0.03	0.15
Perceived external responsibility				0.14**	0.03	0.14
Perceived internal responsibility				0.00	0.03	0.00
R^2			0.05			0.16
ΔR^2						0.11**

Note. $N = 898$; $^{+}p < .05$; $^{*}p < 0.01$; $^{**}p < 0.001$.

knowledge on protective action (M = 2.10; SD = 1.33). Those who received action recommendations alongside the warning message felt significantly better informed than those who did not receive such information, as a one-way ANOVA revealed (Table 9). Asked which adaptation measures they intended to implement after hearing such a warning, on average 15.7 (SD = 3.5) out of a list of 22 measures were indicated. This number again was significantly higher for those who received further information (Table 9). Thus, H4 was confirmed. Descriptive analyzes showed that 20 of the 22 adaptation measures were mentioned more often if the participants had received action recommendations. However, X^2-tests revealed no significant differences. Regarding both variables, the duration of the warning period—whether the warning was for one hot day or three hot days in a row—did not have a significant impact and therefore H5 and H6 both have to be rejected.

4 | DISCUSSION

The research aims of this study were to explain pathways to heat risk protection motivation and behavior using the PADM as a theoretical framework, and to explore which adaptable aspects of heat warnings foster protective behavior. We analyzed these questions with a theory-driven approach in a sample of more than 1400 participants from three cities representing different climates in Germany.

4.1 | Discussion of the hypotheses

Hypotheses 1–3 (Figure 1) stated that context factors as well as psychological factors predict protective action decision making and behavior. The constructs rooted in the PADM explained up to 23% of the variance of the dependent variables, that is, protection motivation, emotion-focused coping, and protective response (Table 6–8). In all regression analyzes, the psychological factors that were added in model 2 increased the R^2 significantly.

Starting with context factors, we investigated the environmental context, risk communication aspects, and personal characteristics. Higher daily mean temperature was associated with lower protection motivation and lower emotion-focused coping. We theorize that heat stress may generally lead to a decrease in cognitive engagement in the topic of heat adaptation and coping. To clarify these effects, we need more research on the impact of longer heat periods (as shown by Lujala & Lein, 2020; Zaval et al., 2014) on perception and behavior. Combining survey data with other methods such as behavioral observations can add to our

TABLE 7 Multiple linear regression testing the impact of context factors and psychological factors on protective response (Hypothesis 2, see Figure 1).

	Model 1			Model 2		
	B	SE(B)	β	B	SE(B)	β
Constant	2.74**	0.44		1.52*	0.59	
Daily mean temperature	0.02	0.01	0.05	0.02	0.01	0.05
Gray area	−0.01	0.00	−0.07	0.00+	0.00	−0.06
Green area	0.00	0.00	−0.02	0.00	0.00	−0.02
Blue area	−0.01	0.01	−0.03	−0.01	0.01	−0.03
Perception of risk communication	−0.03	0.04	−0.02	−0.03	0.04	−0.03
Knowledge of heat warnings	0.38+	0.17	0.07	0.32	0.16	0.06
Female	−0.19	0.12	−0.05	−0.28+	0.12	−0.07
Age	0.00	0.00	−0.03	−0.01	0.00	−0.05
Homeownership	1.31**	0.12	0.35	1.11**	0.12	0.30
Subjective knowledge				−0.07	0.05	−0.05
Perceived future probability				0.00	0.00	−0.01
Perceived personal vulnerability				0.10**	0.03	0.10
Perceived response efficacy				0.06	0.05	0.04
Perceived response costs				−0.14**	0.04	−0.12
Preparedness				0.12*	0.04	0.10
Perceived external responsibility				−0.01	0.06	0.00
Perceived internal responsibility				0.06	0.05	0.04
Protection motivation				0.20**	0.06	0.12
R^2			0.14			0.19
ΔR^2						0.05**

Note. $N = 898$; $^{+}p < 0.05$; $^{*}p < 0.01$; $^{**}p < 0.001$.

understanding of risk perception and behavior depending on temperature and other observable environmental factors (Heidenreich et al., 2021). Regarding neighborhood character indicators, we only see one effect of marginal significance: Respondents living in postal code areas with higher gray proportions tended to show lower protective response. People living in a densely build urban area ("gray") mostly inhabit apartments and are therefore not able to implement many of the listed heat adaptation measures (Table 2). The correlation results suggest that peoples' living environments may impact their risk perception and behavior (Table 5), but more clarification is needed. For future research, it is recommended to depict the participants' neighborhood character on a smaller scale than postal code areas.

Perceiving the local heat risk communication positively only significantly impacted higher levels of emotion-focused coping (Table 9). It seems puzzling why high opinions on official risk communication may increase disengagement while the knowledge of heat warnings has an opposing effect, so further analyzes on these aspects are needed. The vast majority of participants were familiar with heat warnings. They received such warnings mostly via traditional media, such as television and radio, but also via Internet sources and specific apps. This high awareness around heat warnings confirms findings by Capellaro et al. (2015). In recent field research, it was shown that only 10% of people visiting an open air event in a park were aware of heat warnings on the day of their visit (Heidenreich et al., 2021); we therefore have to distinguish between statements about general knowledge and actual knowledge of current warnings. Being aware of heat warnings was associated with increased protective response (Table 8). Thus, addressing heat warnings prominently in risk communication and in everyday life has the potential to motivate citizens to adapt to heat stress.

Regarding personal characteristics, we see that gender differences for protection motivation and protective response, but not for emotion-focused coping. Women showed higher protection motivation whereas men reported higher numbers of building precaution measures as a means of protective response (Tables 5–7). Higher age was a significant predictor in two regression analyzes. Older respondents showed a higher tendency toward protection motivation and also emotion-focused coping. Therefore, it can be helpful to address those emotion-focused coping strategies in targeted communication settings and point out when they might be harmful (if individual protection is urgently needed) and when these strategies can actually help (e.g., if no protection measures are possible). Homeowners reported higher protective response and lower emotion-focused coping. In flood research, it is already well-known that homeownership is a relevant factor for individual adaptation (e.g., Dillenardt

TABLE 8 Multiple linear regression testing the impact of context factors and psychological factors on emotion-focused coping (Hypothesis 3, see Figure 1).

	Model 1			Model 2		
	B	SE(B)	β	B	SE(B)	β
Constant	2.94**	0.26		2.84**	0.34	
Daily mean temperature	−0.04**	0.01	−0.16	−0.03**	0.01	−0.14
Gray area	0.00	0.00	−0.03	0.00	0.00	−0.04
Green area	0.00	0.00	0.06	0.00	0.00	0.05
Blue area	0.01	0.01	0.03	0.01	0.01	0.02
Perception of risk communication	0.12**	0.02	0.19	0.10**	0.02	0.16
Knowledge of heat warnings	−0.27*	0.10	−0.09	−0.23+	0.10	−0.07
Female	0.00	0.07	0.00	0.03	0.07	0.01
Age	0.01**	0.00	0.21	0.01*	0.00	0.15
Homeownership	−0.16+	0.07	−0.07	−0.16+	0.07	−0.08
Subjective knowledge				0.00	0.03	0.00
Perceived future probability				0.00	0.00	0.02
Perceived personal vulnerability				−0.05+	0.02	−0.09
Perceived response efficacy				0.00	0.03	0.00
Perceived response costs				0.12**	0.02	0.18
Preparedness				0.16**	0.03	0.22
Perceived external responsibility				−0.07+	0.03	−0.07
Perceived internal responsibility				−0.04	0.03	−0.05
Protection motivation				−0.02	0.03	−0.02
R^2			0.14			0.23
ΔR^2						0.09**

Note. $N = 819$; $^{+}p < 0.05$; * $p < 0.01$; ** $p < 0.001$.

TABLE 9 Analyzing the situational knowledge on protective action and adaptation intention depending on experimental warnings (Hypotheses 4–6). Means (*M*), standard deviations (*SD*), and two-way ANOVA statistics are reported.

	No info		Info		ANOVA			
	M	*SD*	*M*	*SD*	Effect	*F*	*df*	η^2
Situational knowledge on protective action								
1 day	2.34	1.47	1.93	1.19	Info	24.854**	1, 1408	0.017
3 days	2.21	1.37	1.92	1.19	Duration	0.965	1, 1408	0.001
					Interaction	0.890	1, 1408	0.001
Aggregated adaptation intention								
1 day	15.51	3.74	16.08	3.23	Info	11.089*	1, 1408	0.008
3 days	15.41	3.54	16.08	3.24	Duration	0.069	1, 1408	0.000
					Interaction	0.069	1, 1408	0.000

Note. The four experimental groups' warning messages differed in terms of information (no further information vs. information) and duration of the predicted heat warning (1 day vs. 3 days), as shown in Table 3. Feeling informed after the warning was assessed by a scale from 1 = "I know absolutely what to do"−6 = "I don't know what to do at all." The aggregated adaptation intention represents the number of intended adaptation measures out of a list of 22 possible measures. $N = 1412$, * $p \leq 0.01$; ** $p < 0.001$.

et al., 2022; Grothmann & Reusswig, 2006). Our work supports these findings and points out that ownership can be regarded as a facilitator of protection. Living for rent, however, may hinder people from implementing protective measures at home and possibly facilitate emotion-focused coping strategies.

The context factors explained significant shares of variance in all three regression analyzes (Tables 6–8). Adding psychological factors to the models increased the explained variance in each of the cases; thus, hypotheses 1, 2, and 3 were confirmed. We find no significant influence of subjective knowledge. Interestingly, Beckmann et al. (2021) who recorded actual knowledge using an objective knowledge test also found no clear effect of this variable on adaptation. Meta-analytical findings on predictors of climate adaptation behavior underline the small to nonsignificant effect of subjective and objective knowledge (van Valkengoed & Steg, 2019) and our results confirm this for the topic of heat risk. Consequently, risk communication strategies should not only focus on information dissemination in order to be effective in evoking individual action.

Perceived future probability (as part of threat perception) of heat waves in their own hometown did not predict any of the outcome variables, but we see a positive correlation with protection motivation and a negative correlation with emotion-focused coping (Table 5). Perceiving higher levels of personal vulnerability was associated with higher protection motivation, protective response, and lower emotion-focused coping. This goes in line with other findings on how experiencing negative health impacts personally increases protective behaviors (Esplin et al., 2019).

Protective action perception elements played a significant role, as can be seen in Tables 6–8. Response efficacy positively predicted protection motivation, which contradicts Beckmann et al. (2021) who found efficacy believes to be of no statistical relevance for risk perception and adaptation. Response costs and preparedness were positive predictors of protection motivation but also emotion-focused coping. Furthermore, preparedness was associated positively with protective response and response costs negatively. It surprises that people with high preparedness tended to show more emotion-focused coping. But as the results above showed: protective behavior/response and emotion-focused coping are not diametrically opposite elements. Taken together, it is possible and understandable that people show high protection motivation, protective response as well as emotion-focused coping at the same time.

Higher perceived external responsibility predicted protection motivation, meaning that respondents who found other relevant stakeholders responsible to carry out heat adaptation were also motivated to do it themselves. External responsibility attributions were negatively associated with emotion-focused coping. Perceived individual responsibility was no significant predictor in any of the regression analyzes. It has to be noted, that the scale's alpha is low (0.55), which means that people tended to see their own responsibility differently in the three addressed contexts (home, work, and neighborhood).

Among the regression analyzes, the strongest explanatory power was found for emotion-focused coping. This behavioral outcome has only played a marginal role in the theory-based literature on natural hazards behavior so far (Seebauer & Babcicky, 2021). Emotion-focused coping, or maladaptive coping, as it is called in the PMT (Rogers, 1975, 1983), does not simply mean the absence of protective or adaptive behavior. We see a significant weak negative correlation between emotion-focused coping and protective response (Table 5), but the regression analyzes do not point in diametrically opposing directions. We need more research on emotion-focused coping in order to understand why people engage in such coping strategies and derive implications to foster active coping (Dillenardt et al., 2022; Heidenreich, Köhler, et al., 2020).

The warning experiment underlined the benefits of adding information on adequate behavioral adaptation to the heat warnings. After having received an experimental warning, participants reported significantly higher levels of situational knowledge on protective action if they had received action recommendations along with the warning confirming H4. Participants also intended to carry out more adaptation measures, but this effect was smaller (Table 9). Most adaptation measures were intended more often if action recommendations were presented. The brief, additional action recommendations presumably served as a reminder of existing knowledge (reactivation); it contained general advice, but no specific or detailed adaptation or protection measures. The effect of these action recommendations on intended behavior is thus no mere reproduction of the previously read or heard warning text. Against the background of PADM, we conclude that the risk communication (as a context factor) element of action recommendations is associated to predecision processes (i.e., situational knowledge on protective action) and also protective action decision making (i.e., adaptation intentions). H5 and H6 however, were rejected as no significant differences were seen whether warnings for 1 or 3 days of heat were presented. We assume that some respondents did not picture the abstract threat of a heat wave (Hajat et al., 2006; Li et al., 2015) in the questionnaire situation. Since the warning experiment was located in the last third of the questionnaire, we can expect that the participants had had enough time to think about the topic of heat stress and adaptation. This may explain the overall high level of situational knowledge. Replication studies could reveal how much outcomes differ if an experiment is placed at the beginning of the questionnaire.

Taken together, our results support the PADM. We saw that the addressed context factors concerning environment, risk communication, and personal characteristics predicted protection motivation and behavior. The group of psychological factors also explained significant relevance of the outcome variables. However, the picture on some aspects is not so clear, for example, neighborhood character, subjective knowledge, and internal responsibility. When comparing our work to existing research on PADM, we see that the theory's complexity is both blessing and curse: it allows to include a fuller picture of possible explanatory aspects than PMT (Rogers, 1975, 1983) or other behavioral theories, but at the same time it is less tangible, as the variation in focus setting between existing applications of PADM show. This becomes clear in comparison to the most recent work on PADM and heat stress (Beckmann et al., 2021) which shows a very different operationalization than this article. We see an urgent need for standardized and validated survey instruments on PADM's (and other theories') constructs.

This would allow more comparable research and more robust recommendations.

4.2 | Limitations

In order to achieve a more diverse sample, we carried out the survey both via telephone and online. This mix of methods also entailed difficulties. Across research fields, the choice of survey mode can have an impact on the sample and the participants' response behavior (Berrens et al., 2003; Zhang et al., 2017). Self-selection bias may play a greater role in online surveys (Bethlehem, 2010), but since many people no longer have a landline phone, a mere telephone-based survey is not likely to represent the addressed population. Therefore, we encourage researchers to carry out future surveys through a combination of channels, for example, via telephone, by mail, and online, and to evaluate possible methodological effects.

We conducted our survey in three medium-sized German cities. Heat waves have a stronger impact in cities that are larger and more densely populated (Zhou et al., 2017), although rural areas can also be affected by heat stress. In Germany as of 2017, around two thirds of the inhabitants live in rural areas (Otto, Göpfert et al., 2021; Otto, Kern, et al., 2021). The three cities differ in terms of their vulnerability to climate change (UBA, 2015), and show the variability of German cities in this respect. However, adaptation readiness and climate policies also vary between cities, as analyzes of 104 German cities showed (Otto, Göpfert et al., 2021; Otto, Kern, et al., 2021). Currently, there is not much known about small and medium-sized cities' climate change adaptation in Germany (Häußler & Haupt, 2021). Our results should be verified in a broader and also rural sample before conclusions are drawn for the general German population.

To keep the questionnaire short some PADM constructs were only covered by a limited number of items and therefore not all aspects the theory covers were captured. Some aspects that could be addressed in future questionnaires in this domain are nonmonetary behavioral costs and past behavioral adaptation apart from building precaution. In the warning experiment only adaptation intentions were recorded, no actual adaptive behavior. Therefore, interpretations of the warnings' effects on behavior should be made with care. A recent study from Switzerland, however, compared actual behavior after receiving real flood warnings to behavioral intentions after receiving warnings under experimental conditions (Weyrich et al., 2020). The participants in the scenario-based experimental setting perceived and understood the warning similarly well compared to people who received real-time warnings from a weather app, and the authors found no significant interaction effects between setting and warning type. Therefore, we assume that the stated behavioral intentions are reliable proxies for actual behavior. Still, we recommend further research on responses to real heat warnings.

5 | CONCLUSION AND OUTLOOK

Heat waves will continue to take place across the world presenting a threat to health and life, and therefore a focus of scientific research needs to be on citizens' adaptation and protection (Campbell et al., 2018). The aim of this research was to explain the pathways from risk communication and risk perception to individual adaptation (protective behavior). Since cities are more prone to heat stress, we carried out our research in an urban sample. We chose a theory-driven approach and applied the PADM as a framework to explain protective action decision making and behavior in the context of heat risk. This is one of the first applications of the PADM in the heat context, and the theory proved to be a helpful basis for our research; nevertheless, we see the need for further scientific clarification of the impacts of some model components. We further explored which aspects of a heat warning message foster perception and protective behavior, and found that additional information on individual adaptation measures led to a better understanding and also higher intended behavioral adaptation. Heat warnings play a crucial role in risk communication, aiming to motivate individual action and preparedness, and to limit adverse effects of extreme weather. Whenever possible, those warnings should not only include the time and expected temperature of the heat waves, but should also be accompanied by adaptation information and recommended actions.

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