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Human extreme heat protective behaviours: the effects of physical risks, psychological perception, and public measures

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Individual actions can mitigate the consequences of extreme heat. Therefore, understanding the mechanism of protective behaviours against extreme heat is critical. Although extreme heat protective behaviours have been widely mentioned, the roles of psychological risk perception and public restraint are poorly understood. In this study, we developed a physical-measure-psychosocial model (PMP) to reveal the intrinsic motivation for protective behaviours during extreme heat based on a nationwide survey in China (n = 1791). The results showed that (1) high levels of physical risk perception promote outdoor, indoor, and traffic protective behaviours. Psychological risk perception is positively associated with outdoor and indoor protective behaviours but is not significantly associated with traffic protective behaviour. (2) There are differences in the main paths from heat exposure to outdoor, indoor, and traffic protective behaviours. The indirect effect controlled by physical risk is the main path from exposure to outdoor and traffic protective behaviours, while the direct effect of heat exposure is the strongest pathway for indoor protective behaviour. (3) Enhanced facility conditions are linked to reduced physical risk and psychological risk perception. Subsidies have a significant effect on traffic protective behaviour, and warnings significantly affect outdoor protective behaviour. The direct effect of warning systems on outdoor protective behaviour is greater than the indirect effect mediated by psychological risk perception. (4) Multigroup analysis based on structural equation models revealed a certain degree of robustness among the different gender, age, education level, and income level groups. This study enables us to understand the underlying mechanisms of extreme heat behaviours and support policy-makers in effective mitigation practices.

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Introduction

The extreme heat in the summer of 2022 engulfed a large area of the northern hemisphere. In China, a total of 71 weather stations broke historical temperature records, with some above 44 °C (Ji, 2022). Smelting heat waves are a major public health challenge worldwide (Coumou, 2011; Gasparrini et al. 2015; Shi et al. 2018; Sun et al. 2017). In 2022, a heatwave in Europe claimed the lives of 61,672 individuals (Ballester et al. 2023), and the projected impact of global warming is expected to exacerbate the risks linked to extreme heat-related mortality (Romanello et al. 2023). Global warming exacerbates extreme heat. Even a 1.5 °C global warming scenario combined with improved adaptation will double the annual heat-induced mortality in China to 48.8–67.1 per million (Wang et al. 2019). A lack of individual adaptation to high temperatures and insufficient government emergency management are likely to lead to more serious consequences (Ramakreshnan et al. 2019). Therefore, research on the process of human protective behaviours and public measure roles during extreme heat could be helpful for the construction of healthy residential environments.

Adequate individual preparation is an effective measure to avoid the danger of high temperatures. Personal behavioural patterns in hot temperatures have been widely studied (Gautam et al. 2020; Kim and Brown, 2022). For example, Ma et al. (2021) observed people's travel behaviour patterns in parks during hot weather. Shih et al. (2022) analysed the use of high-temperature umbrellas among individuals of varying ages, sexes, and health conditions with descriptive statistics. Previous studies focused only on simplistic demographic descriptions, and a knowledge gap remains regarding the intrinsic motivation for individual protective behaviours with regard to psychological and social processes. Previous studies have mentioned the roles of perceived severity, perceived dread, and perceived controllability in behavioural protection under high temperatures (Ban et al. 2019). However, to our knowledge, no studies have linked physical risk to psychological risk perception and protective behaviour processes when quantifying behaviours during extreme heat.

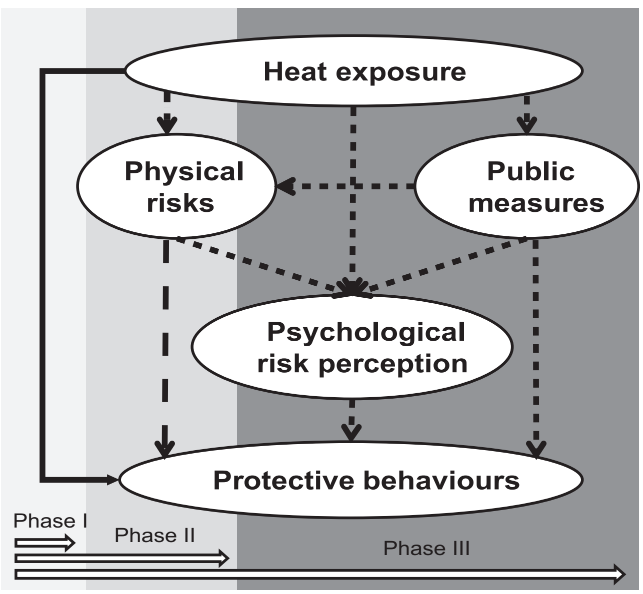

Fig. 1 Model framework of heat protective behaviours. Notes: The white arrows represent the research stage of the topic. Phase I represents research on heat exposure (external environment); Phase II focuses on the physical risks caused by heat exposure; and Phase III represents our innovative approach to incorporating psychological and public measures into the research framework.

An abundance of evidence supports the relationship between heat exposure and health disorders. Prolonged exposure to high temperatures causes excess deaths (He et al. 2022; Yazar et al. 2022; Zhao et al. 2022) and heat-related illnesses, such as sleep disorders, respiratory diseases, cardiovascular disease, kidney injury, and mental health issues (Hwong et al. 2022; Li et al. 2022; Morais et al. 2021; Vaidyanathan et al. 2019; Zhao et al. 2019). People with physical risk experiences tend to have greater psychological risk perceptions and protective behaviour (Ban et al. 2019; Musacchio et al. 2021). In addition, governmental decisions largely shape the magnitude of heat damage, and the government is committed to benefiting citizens through adequate facilities, accurate early warning systems, emergency response plans, and optimized urban structures (Wang et al. 2019). To address thermal discomfort, facilities are designed to cope with high temperatures, such as green spaces and park services (Javadi and Nasrollahi, 2021; Niu et al. 2022). In many cases, residents fail to take adequate precautionary actions for extreme weather events due to insufficient risk awareness and lack of knowledge. Government intervention is a fast and effective way to reduce health risks and promote accurate psychological risk perception (Lavelle et al. 2015). An early warning system can realign perceived risk to compensate for discrepancies with actual risk, thereby prompting action (Sinclair et al. 2021). A heat subsidy is another initiative proposed by the government to help people who must work in the heat avoid financial problems and reduce emotional dissatisfaction. However, the impact of these government interventions on public health risk, psychological risk perception, and protective behaviour remains unexplored.

Despite accumulating evidence that protective behaviours are influenced by local weather, little work has explored the underlying psychological processes involved in these actions and how public management elements act on individual responses to hot weather events. We address this knowledge gap by establishing a physical-measure-psychosocial (PMP) model to systematically elucidate the underlying intrinsic motivation for protective behaviours. In this study, we provide a theoretical framework to examine whether, how, and to what extent heat exposure, physical risk, psychological risk perception, and public measures influence protective behaviours. Important questions include which factors promote protective actions, whether psychological risk perception is an intermediary that affects the intensity of heat protective behaviour, how public measures such as outdoor facilities, high-temperature subsidies, and early warning systems work, and how effective they are. This study offers a novel mechanism to explicate the intrinsic process of heat protective behaviour.

Model framework design

We created a theoretical model of heat protective behaviour that integrates physical factors, psychological factors, and public measures (Fig. 1). The framework is designed to specifically address the mediating effect of physical risk and psychological risk perception as well as the effects of public measures.

Heat exposure. A stream of literature has proposed that heat exposure leads to poor ability of metabolic and body temperature regulation, which manifest as various disorders of the respiratory system, cardiovascular system, gastrointestinal system, and nervous system (Ebi et al. 2021). Due to the challenge of precisely ascertaining the duration of heat exposure at a specific temperature, we defined the air temperature as the exposure factor. Our primary objective was not to investigate real-time individual responses but rather to explore disparities in individual reactions under the influence of climatic backgrounds and short-term weather fluctuations. Several theories posit that individuals' beliefs about heat risk seem to be based on short-lived weather memory. Warm weather conditions may increase memory of heat events (Zaval et al. 2014). Therefore, we adopted the 7-day temperature and the temperature of the day of access to the survey as the exposure factors to determine the impact of ambient temperature changes on individuals' behavioural responses. We calculated the mean and maximum temperatures for both the survey participation day and the 7-day window inclusive of the survey day along with the preceding 6 days. A survey conducted during ongoing hot weather may be helpful for accurately measuring physical risk. Therefore, we conducted a questionnaire survey in July and August 2021 and collected the hourly temperatures at city meteorological sites during the survey period. These data were downloaded from the Chinese meteorological data sharing website. We matched the temperature of the monitoring station near the participants to serve as the exposure factor data according to the survey dates and sites.

H1a: A higher level of heat exposure leads to higher heat-related physical risk.

H1b: A higher level of heat exposure leads to greater psychological risk perception.

H1c: Heat exposure is positively associated with outdoor protective behaviour.

H1d: Heat exposure is positively associated with indoor protective behaviour.

H1e: Heat exposure positively affects traffic protective behaviour.

H1f: Heat exposure promotes high-temperature warnings.

Physical risks. Previous broad surveys have suggested that risk experience plays an important role in shaping individuals' psychological risk perception (Rufat and Botzen, 2022; Yazar et al. 2022). For example, flood experience significantly increases the degree of people's perceived risk frequency and duration (Rufat and Botzen, 2022). Evidence indicates that people who witness a disaster are more risk aware and willing to take response actions (Ban et al. 2017; Boss et al. 2015). In this study, we defined physical risk as the frequency of symptoms arising from heat exposure. Five indicators were identified to characterize people's physical risk during hot weather: sleep disorders, tachypnoea and cardiovascular disease, tiredness and loss of appetite, depression, and irritability. Based on these previous studies, the following hypotheses are formulated:

H2a: Physical risk is associated with heat-related psychological risk perception.

H2b: Physical risk has a positive influence on outdoor protective behaviour.

H2c: Physical risk has a positive influence on indoor protective behaviour.

H2d: Physical risk has a positive influence on traffic protective behaviour.

Psychological risk perception. Psychological risk perception is an individual's assessment of threats and involves a series of psychological processes (Slovic, 1987). Previous theories propose that psychological perception is critical in motivating individuals to adopt protective behaviour (Rogers, 1975). The overestimation of risks causes people to be overwhelmed by fear, while the underestimation of risks leads people to neglect precautions (Azadi et al. 2019). An extensive body of studies has claimed that psychological risk perception can better predict public behaviours (Ban et al. 2017; Zhu et al. 2016). Generally, the multi-dimensionality of risk perception is dominated by risk severity, risk probability, concern about consequences, and behavioural control (Doane et al. 2016; Tang et al. 2021). Risk severity reflects how serious an anticipated threat is perceived to be. The prior literature has shown the positive effects of risk severity on coping behaviours (Boss et al. 2015). Perceived probability refers to the subjective evaluation of the likelihood of encountering threatening events. People who perceive a high chance of risk occurrence are more likely to implement protective behaviours (Zhou et al. 2020). Risk concerns pertain to the appraisal of worries associated with potential ramifications. Behavioural control refers to individuals' belief in their ability to perform risk prevention behaviours and the effectiveness of the action for eliminating potential harm (Maddux and Rogers, 1983; Rogers, 1975). When individuals are confident in the controllability of risk, they are more likely to act against threats. According to previous studies (Ban et al. 2019; Mooney et al. 2021), psychological risk perception is indicated by perceived risk probability (the possibility of heat consequences in the coming years), severity (the perceived magnitude of heat impacts), concern (worry about the impact of heat consequences on life and work), and controllability (the perceived controllability of high temperature hazards) in this study. Therefore, the following hypotheses are proposed:

H3a. Individuals with a high level of psychological risk perception are more willing to take outdoor adaptive actions.

H3b. Individuals with a high level of psychological risk perception are more willing to take indoor adaptive actions.

H3c.Individuals with a high level of psychological risk perception are more willing to take traffic adaptive actions.

Public measures. Based on planned behaviour theory, social norms are important catalysts for protective behaviour. In our research model, we propose public measures as a crucial predictor variable as public information has been found to be essential for triggering mitigating behaviour against high temperatures. Public measures include facilities, high-temperature subsidies, and heat wave warnings.

Parks, green spaces, and supporting recreational facilities can help people rest in the shade, thereby reducing the physical risk of heat exposure. Therefore, a perfect green space system can reduce people's perception of heat risk. Previous research has shown that heatwaves are associated with significant risk in low-green areas (Son et al. 2022). Space-poor households are more likely to frequently seek shade in city parks (Lo et al. 2022). Distance, efficient green shade, and good facilities play important roles in park visit decisions (Veitch et al. 2022; Wang et al. 2021). Therefore, we use residents' self-reported satisfaction with green spaces, community gazebos, seats under tree shade, and distance to the nearest park to express the condition of outdoor facilities. We assume the following:

H4a: People who have more favourable facility conditions have lower levels of physical risk.

H4b: People who have better facility conditions have lower perceptions of psychological risk.

An effective warning system can raise public awareness of self-protection and activate intervention measures from government authorities (Yang et al. 2022). We evaluated warning measures using the frequency of warning information releases. Subsidies are important predictors of public environmental protection behaviour, such as the consumption behaviour of carbon-sink fishery products (Zheng and Yu, 2022) and agricultural waste recycling behaviours (Zhou et al. 2021). We speculate that high-temperature subsidies provide financial support to promote certain protective behaviours that require payment. We asked participants to report their attitudes towards the level of subsidies received.

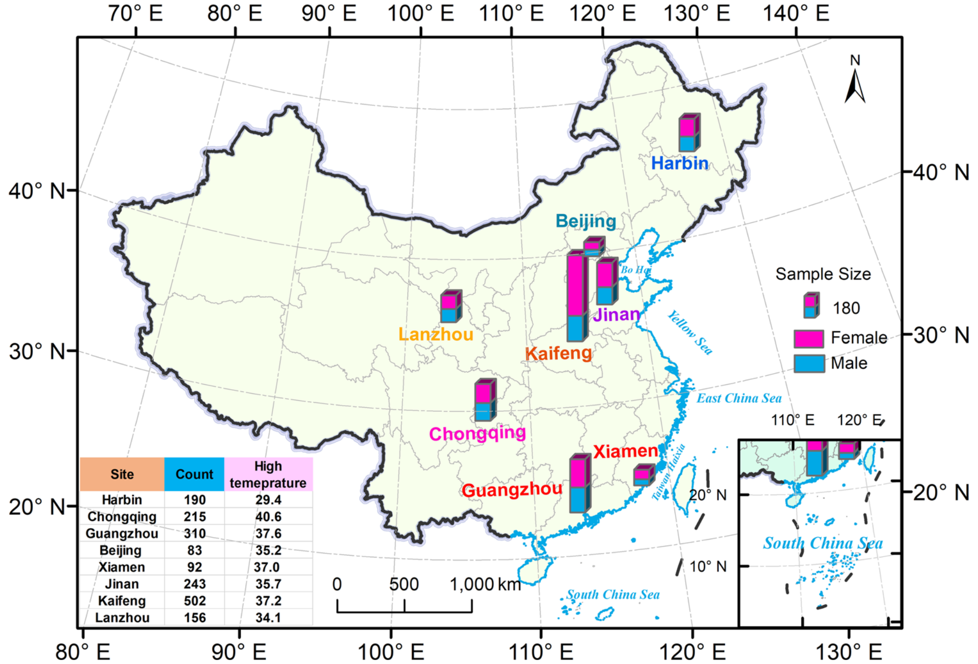

Fig. 2 The geographical distribution of the survey cities.

H4c: High-temperature warnings are positively correlated with psychological risk perception.

H4d: High-temperature warnings positively affect outdoor protective behaviour.

H4e: High-temperature warnings positively affect indoor protective behaviour.

H4f: High-temperature warnings positively affect traffic protective behaviour.

H4g: High-temperature subsidies promote traffic protective behaviour.

Methods

Survey procedures. A trial study with 244 respondents was conducted to determine the readability and effectiveness of the questionnaire, and minor modifications were made to the questionnaire based on pretests prior to the official survey launch. Cities were selected by taking into account the stratification of recorded heat-related mortality statistics and multiclimatic coverage. The final questionnaire survey was administered in the cities of Chongqing, Guangzhou, Xiamen, Beijing, Jinan, Kaifeng, Lanzhou, and Harbin during a high-temperature period from July to August 2021 (Fig. 2). All eight cities in China have a wide range of climatic conditions. The questionnaire was administered through the online survey platforms "wjx.cn" and "txwj.cn". Small rewards were provided to incentivize participants to respond. A total of 2285 respondents completed the survey. To ensure the integrity of the data, incomplete and logically erroneous responses were excluded, as were questionnaires that lacked the temperature values necessary to match heat exposure. Additionally, samples with completion times of less than 100 s were excluded from the analysis to ensure conscientious responses. Ultimately, a total of 1791 valid questionnaires were utilized for structural equation modelling.

Questionnaire measurement. The participants were asked to complete a 28-item online survey that included sociodemographic information, physical risk during extreme heat (5 practices), heat psychological risk perception (4 practices), outdoor facility satisfaction (4 practices), warnings (1 practice), subsidies (1 practice) and protective behaviours (6 practices). The participants indicated the extent to which they encountered health risks due to high temperature on a 5-point Likert scale (1 = not at all to 5 = severely), including sleep disorders, tachypnoea and cardiovascular disease, tiredness and loss of appetite, depression, and irritability. Heat psychological risk perception was also indicated on a 5-point Likert scale to rate the surrounding risk severity, risk probability, risk consequence concerns, and risk controllability. The situations in everyday life primarily consist of outdoor, indoor, and transportation settings. Therefore, as suggested by Ban et al. (2019), three protective behaviour categories were classified: (1) outdoor protective behaviours, including adopting sunshade behaviour (e.g., umbrella, sunscreen clothing), adjusting travel times, and cancelling nonessential activities; (2) indoor protective behaviours, including changes in air-conditioner use and fan use; and (3) traffic protective behaviours, including taking a taxi or car to reduce heat exposure. Since we focused only on changes in protective behaviour caused by high temperatures, the increase in protective behaviour was positive. The degree to which protective behaviour increased in response to high temperatures was described using a four-point scale (1 = no change, 2 = a slight increase, 3 = moderate increase, 4 = a large increase). We represented the level of urban heat mitigation facilities through residents' satisfaction with the relevant facilities. Drawing on previous research (Kabisch et al. 2021; Liu et al. 2020; Mouratidis, 2019), we evaluated the participants' level of contentment with various facilities, including the green space area, number of community pavilions, availability of rest facilities under canopies, and proximity of the nearest park to the respondents' homes. The participants rated these factors on a scale ranging from 1 ("very dissatisfied") to 5 ("very satisfied"). Subsidies were measured on a five-point scale ranging from "none" to "very much". Respondents were asked to rate the frequency of the warning information they received on a scale ranging from 1 to 5, with higher scores indicating a greater frequency of warning notifications. In addition, we asked the respondents to submit their sociodemographic characteristics, including sex, age, education, and monthly income.

Statistical analysis. Structural equation model (SEM) analyses included exploratory factor analysis, confirmatory factor analysis, structural equation model construction and modification, and

Table 1 Demographic characteristics of respondents.

Characteristics	Items	N	Frequency
Gender	Male	737	41%
	Female	1054	59%
Age	<18	43	2%
	19–29	750	42%
	30–39	597	33%
	40–49	144	8%
	50–59	243	14%
	≥60	14	1%
Education	Senior high school below	141	8%
	Senior high school	230	13%
	Bachelor	1138	63%
	Master	210	12%
	PhD	72	4%
Monthly income	<2500 RMB	370	21%
	2,500–4,999 RMB	585	32%
	5,000–9,999 RMB	567	32%
	10,000–29,999 RMB	204	11%
	30,000–50,000 RMB	29	2%
	>50,000 RMB	36	2%

assessment of the path coefficients. We first checked the validity of the questionnaire items and conducted an exploratory factor analysis to determine which items should be classified as the same latent variable. The confirmatory factor analysis examined the reliability of the observed variable (question items) explaining the latent variable. We investigated the association patterns of the independent variables (exposure, physical risk, psychological risk perception, facility satisfaction, warning, and subsidy) with protective behaviour using structural equation modelling. In addition, we performed a subgroup analysis to examine the effect of demographic characteristics on the theoretical model. We divided the respondents according to age into young (<40 years) or middle-aged and elderly (≥40 years). Educational levels were divided into low (below high school, high school) and high (bachelor's, master's, or doctorate level). Income levels were divided into the categories low (<30,000 RMB) and high (≥30,000 RMB). Exploratory factor analyses were performed using IBM PASW (SPSS) S statistics 22.0, and other analyses were performed using IBM SPSS AMOS 24.0.

Results

Accuracy of the protective behaviour model. Table 1 presents the characteristics of the pooled study sample. Of the 1791 individuals, 59% were female and 41% were male. The majority of participants were young (75%), followed by middle-aged participants (22%). Table 2 displays the mean values for each question as well as the absolute values of skewness and kurtosis. The levels of sleep disturbances and irritability experienced at high temperatures were relatively high, with average scores of 2.9 and 2.97, respectively. In terms of psychological risk perception, the participants self-reported the highest scores for risk probability.

The reliability of the questionnaire is fundamental to the research. We used the KMO-Bartlett test and Cronbach's α to determine the reliability of the data. The results showed that the KMO score was 0.739 and Cronbach's α was 0.76, which signifies good reliability. The Cronbach's αs for heat exposure, physical risk, psychological risk perception, and facility satisfaction were 0.804, 0.852 0.711, and 0.862, respectively. Before performing SEM, confirmatory factor analysis was conducted on the design factors and their measurement dimensions (Table 2). The latent scale was purified by item removal and chunking. The modification indices revealed that the error terms HE2 and HE3 were highly correlated with multiple items; thus, they were removed. Table S1 shows the specification indicator structure for the initial model. The reliability and validity of the measurement model were tested by confirmatory factor analysis. The validity of the model was tested for convergent validity and discriminant validity. Convergent validity was determined by average extraction variation (AVE) and CR values (Ghansah et al. 2022) (Supplementary Table S2). The square root of the AVE for all the latent variables was greater than the correlation coefficient (Supplementary Table S3), indicating that the measurement model had good discriminant validity. We based on modification indices from SPSS AMOS (version 24) to add covariance and causal relationships between the error terms and the measured variables. All modifications ensured that the results made theoretical sense (Ajayi and Oyedele, 2018). Our theoretical model of heat protective behaviour fit well [$\chi 2/df = 3.965$, RMSEA = 0.04, NFI = 0.945, RFI = 0.932, IFI = 0.959, TLI = 0.949, CFI = 0.958].

Hypothesis results of the protective behaviour model. The results of the hypothesized path are presented in Fig. 3 and Table 3. The results show that exposure was significantly positively correlated with physical risk (0.17***), psychological risk perception (0.06*), and warning (0.13***) (Fig. 3). The effect of heat exposure on indoor protective behaviour was significant (0.35***), but there was no significant effect on outdoor or traffic protective behaviours. Residents who experience physical risks had a higher perception of psychological risk (0.56***), which was associated with higher levels of outdoor protective behaviour (0.22***), indoor protective behaviour (0.15***), and traffic protective behaviour (0.22***). Psychological risk perception was significantly correlated with outdoor protective behaviour (0.18***) and indoor protective behaviour (0.21***) but was not significantly correlated with traffic protective behaviour. Facility satisfaction had a significant negative impact on physical risk perception (−0.29***). The warning had a significant positive impact on psychological risk perception (0.22***) and outdoor protective behaviour (0.09***), but its effects on indoor protective behaviour and traffic protective behaviours were not significant. As expected, subsidies had a significant but slight effect on traffic protective behaviour.

Direct and indirect contributions to protective behaviour. Heat exposure had direct and indirect effects on psychological risk perception. Its direct effect was 0.06, and the indirect effect through physical risk was 0.12. The indirect effect of heat exposure through physical risk and psychological risk perception on outdoor protective behaviour (0.08) was greater than the direct effect (0.035), while the opposite was true for indoor protective behaviour (Fig. 4). The direct effects of physical risk on outdoor protective behaviour (0.218) and traffic behaviour (0.217) were greater than the indirect effects mediated by psychological risk perception (outdoor protective behaviour 0.1, traffic behaviour 0.02). Similarly, the direct effect of warnings on outdoor protective behaviour (0.086) was greater than the indirect effect (0.039). These results suggest an overall shift in the main influencing path for outdoor protective behaviour, traffic behaviour, and indoor protective behaviour. The total effects of heat exposure, physical risk, psychological risk perception, and warning on outdoor and indoor protective behaviours were much greater than for traffic behaviour. Physical risk (0.32) was the strongest predictor of outdoor protective behaviour, followed by psychological risk perception (0.18) and warning (0.12) (Fig. 4). For traffic protective behaviour, physical risk (0.24) was the strongest predictor, and the other factors were weaker. Our model revealed that heat exposure (0.41) had the strongest effect on indoor

Table 2 Survey items explanation and descriptive statistics results.

Code	Explaining	Mean	Skewness	Kurtosis
HE1	Average air temperature in a week	26.49	−0.238	0.181
HE2	Maximum air temperature in a week	33.35	0.534	0.604
HE3	Average air temperature in a day	27.22	−0.873	0.432
HE4	Maximum air temperature in a day	31.17	−0.435	−0.189
PR1	Sleep disorder	2.9	−0.130	−0.684
PR2	Tachypnea and cardiovascular disease	2.43	0.256	−0.737
PR3	Tiredness and digestive upsets	2.77	−0.007	−0.696
PR4	Depression	2.76	0.006	−0.731
PR5	Irritability	2.97	−0.117	−0.828
PRP1	Severity	2.99	0.228	−0.551
PRP2	Probability	3.90	−1.100	1.853
PRP3	Concerns	3.10	−0.054	−0.691
PRP4	Controllability	3.3	−0.251	−0.373
FC1	Green area	3.40	−0.133	0.203
FC2	Number of community gazebos	2.98	0.134	−0.078
FC3	Number of seats under trees	2.94	0.111	−0.235
FC4	The distance from the nearest park to your home	3.21	−0.226	−0.251
Warning	Warning information	3.15	−0.102	−0.902
Subsidy	Subsidy condition	1.69	0.999	−0.156
OP1	Sunshade behaviour (shading, wearing an umbrella/wearing a sun hat/sun shirt/sunscreen)	2.93	−0.541	−0.890
OP2	Adjusting travel time	3.05	−0.609	−0.535
OP3	Cancelling non-essential activities	3.04	−0.670	−0.510
TP	Car and taxi use change	2.49	−0.113	−0.788
IP1	Air conditioner use	3.385	−1.298	0.675
IP2	Fan use	3.173	−0.887	−0.322

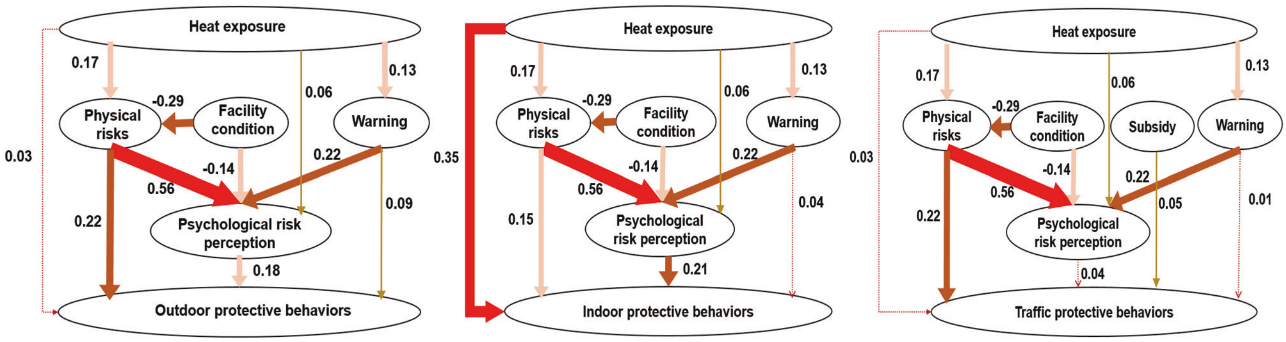

Fig. 3 Model of protective behaviour during extreme heat. Note: Dashed lines represent nonsignificant differences ($P > 0.05$), which indicate nonsupported paths. The solid lines represent significant differences ($P < 0.05$) and indicate supported paths.

protective behaviour. The proposed model was highly predictive and explained 14% of the difference in outdoor protective behaviour, 8% of the difference in traffic behaviour, and 27% of the difference in participants' indoor protective behaviours. In this section, ∗significance at an α level of 0.05, ∗∗significance at an α level of 0.01, and ∗∗∗significance at an α level of 0.001.

Model structures among population groups. To examine the general applicability of our model and explore the existence of potential moderating factors, we conducted a series of subgroup analyses using the multiple-group structural equation modelling approach. This approach allowed us to investigate potential variations in factor structures and path parameters among different groups, thereby enhancing our understanding of the overall model's robustness. We explored the model structure differences of respondents with different sex, age, education, and income profiles through multigroup analysis. Further pooled sample distributions according to sex, age, education, and income are provided in Table S4. Model goodness-of-fit tests were performed on male and female samples, young, middle-aged and elderly samples, high-education and low-education samples, and high-income and low-income samples. The fit models were all effective with qualified goodness of fit (Table 4), and cross-group comparisons could be made. We compared the unconstrained structure path and the fixed structure path to test group differences. The results revealed no significant differences across subgroups with regard to sex, age, education, or income, demonstrating the robustness of the theoretical model framework. Table 5 presents the path coefficients differentiated by sex, age, education level, and income level.

Warning information access among different groups. High-temperature warnings and understanding of heat-related impacts play important roles in promoting risk awareness and heat protective behaviour. To further strengthen the dissemination of risk awareness and drive behavioural adaptation, we explored how various populations acquire warning information and their perspectives on the heat-affected population. In our study, participants reported that SMS alerts and mobile weather forecasts were regarded as the main sources of heat risk warnings. Group preferences showed that younger respondents paid more attention to mobile phone weather forecasts, while the proportion of older

Table 3 The path coefficients of latent variables in structural equation model and hypotheses tests.

Hypothesis	Path	Estimate	*P*-values	Results
H1a	Heat exposure→Physical risks	0.17	<0.001	Support
H1b	Heat exposure→Psychological risk perception	0.06	0.031	Support
H1c	Heat exposure→Outdoor protective behaviour	0.03	0.219	Reject
H1d	Heat exposure→Indoor protective behaviour	0.35	<0.001	Support
H1e	Heat exposure→Traffic protective behaviour	0.03	0.297	Reject
H1f	Heat exposure→High-temperature warning	0.13	<0.001	Support
H2a	Physical risks→Psychological risk perception	0.56	<0.001	Support
H2b	Physical risks→Outdoor protective behaviour	0.22	<0.001	Support
H2c	Physical risks→Indoor protective behaviour	0.15	<0.001	Support
H2d	Physical risks→Traffic protective behaviour	0.22	<0.001	Support
H3a	Psychological risk perception→Outdoor protective behaviour	0.18	<0.001	Support
H3b	Psychological risk perception→Indoor protective behaviour	0.21	<0.001	Support
H3c	Psychological risk perception→Traffic protective behaviour	0.04	0.38	Reject
H4a	Facility condition→Physical risks	−0.29	<0.001	Support
H4b	Facility condition→Psychological risk perception	−0.14	<0.001	Support
H4c	High-temperature warning→Psychological risk perception	0.22	<0.001	Support
H4d	High-temperature warning→Outdoor protective behaviour	0.09	0.002	Support
H4e	High-temperature warning→Indoor protective behaviour	0.04	0.239	Reject
H4f	High-temperature warning→Traffic protective behaviour	0.01	0.718	Reject
H4g	High-temperature subsidy→Traffic protective behaviour	0.05	0.046	Support

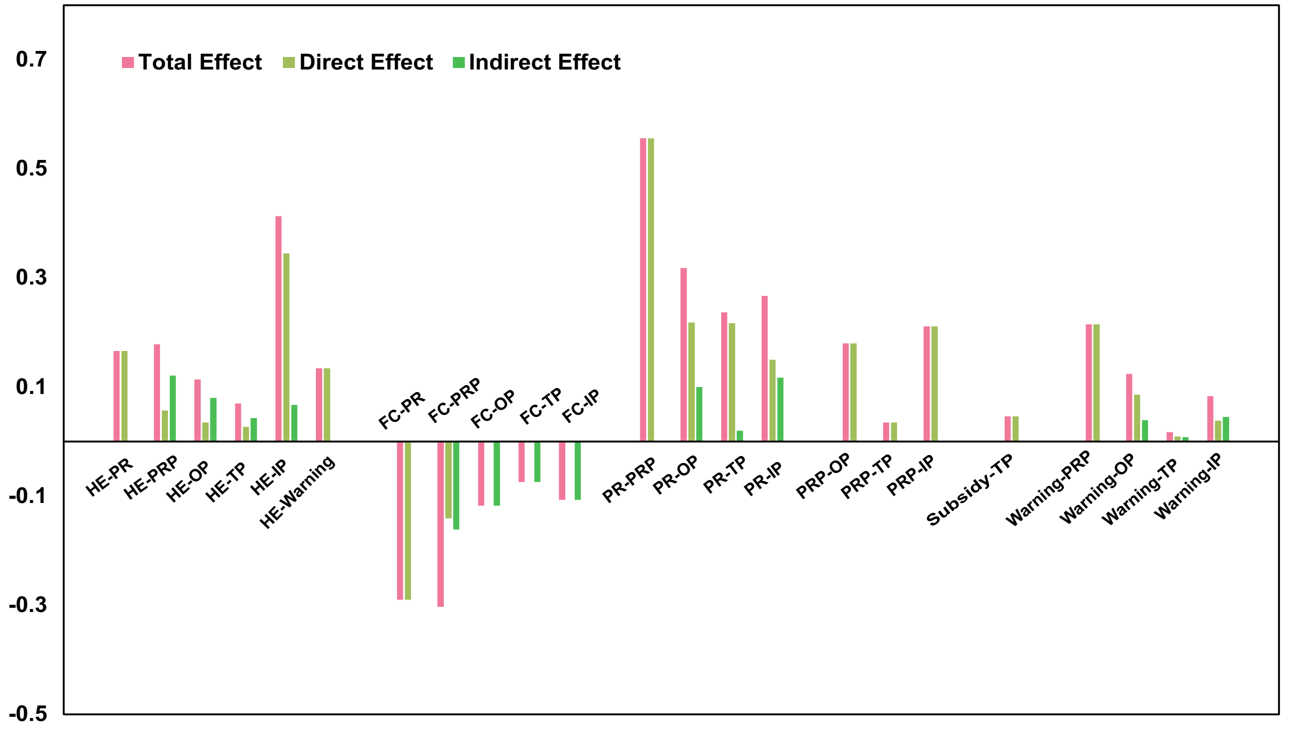

Fig. 4 The standardized direct effect, indirect effect and total effect of variables. Note: HE heat exposure, PR physical risk, PRP psychological risk perception, FC outdoor facility condition, OP outdoor protective behaviours, IP indoor protective behaviours, TP traffic protective behaviours.

Table 4 Goodness of fit for model test.

Groups	χ2/df	RMSEA	NFI	RFI	IFI	TLI	CFI
Male	2.301	0.042	0.927	0.909	0.957	0.947	0.957
Female	2.982	0.043	0.930	0.913	0.952	0.940	0.952
Youth	3.550	0.043	0.937	0.922	0.954	0.943	0.954
Middle-aged and elderly	1.558	0.037	0.910	0.889	0.966	0.957	0.965
Low-education	2.060	0.0538	0.894	0.869	0.943	0.928	0.942
High-education	3.163	0.039	0.941	0.928	0.959	0.949	0.959
Low-income	3.536	0.041	0.944	0.930	0.959	0.949	0.959
High-income	1.421	0.040	0.872	0.842	0.958	0.947	0.957

Table 5 Standardized path coefficients for subgroups with different characteristics.

	Male	Female	Youth	Middle-aged and elderly	Low-education	High-education	Low-income	High-income
HE--- > PR	0.110*	0.216***	0.187***	0.044	0.219***	0.163***	0.154***	0.199**
FC--- > PR	−0.269***	−0.311***	−0.311***	−0.251***	−0.332***	−0.253***	−0.317***	−0.115
HE---> Warning	0.136***	0.132***	0.135***	0.133*	0.166**	0.125***	0.116***	0.217***
PR--- > PRP	0.568***	0.547***	0.577***	0.515***	0.493***	0.574***	0.531***	0.675***
FC--- > PRP	−0.128**	−0.153***	−0.106***	−0.225***	−0.068	−0.162**	−0.157***	−0.081
Warning---> PRP	0.259***	0.186***	0.210***	0.231***	0.182***	0.225***	0.214***	0.221*
HE--- > PRP	0.037	0.077*	0.062*	0.003	0.038	0.061*	0.064*	0.019***
PRP--- > OP	0.187**	0.244***	0.213***	0.100	0.213*	0.172**	0.155**	0.333
HE--- > OP	0.059	−0.004	0.051	−0.032	0.116	0.021	0.036	0.012*
PR--- > OP	0.251***	0.197***	0.179***	0.296***	0.167*	0.205***	0.217***	0.189
Warning---> OP	0.136**	0.051	0.054	0.192***	0.135*	0.074*	0.088**	0.068
HE--- > IP	0.362***	0.323***	0.380***	0.218***	0.312***	0.357***	0.343***	0.369
PR--- > IP	0.166*	0.127*	0.121*	0.181*	0.167	0.126*	0.149**	0.191
PRP--- > IP	0.196*	0.251***	0.215***	0.256*	0.074	0.256***	0.198***	0.303
Warning--- > IP	0.090	−0.004	0.059	−0.017	0.036	0.041	0.036	0.063
PR--- > TP	0.184**	0.218***	0.205***	0.150*	0.404***	0.137***	0.219***	0.189
PRP--- > TP	0.052	0.058	0.043	0.095	−0.080	0.071	0.051	−0.048
HE--- > TP	0.010	0.034	0.038	−0.050	−0.108*	0.068*	0.024	0.036*
Subsidy--- > TP	0.034	0.064*	0.019	0.173***	0.076	0.027	0.057*	−0.026
Warning--- > TP	0.026	−0.009	0.014	−0.007	0.071	−0.004	0.014	0.010

Note: Symbols *, **, *** indicate the significance levels of 0.05, 0.01, and 0.001, respectively.

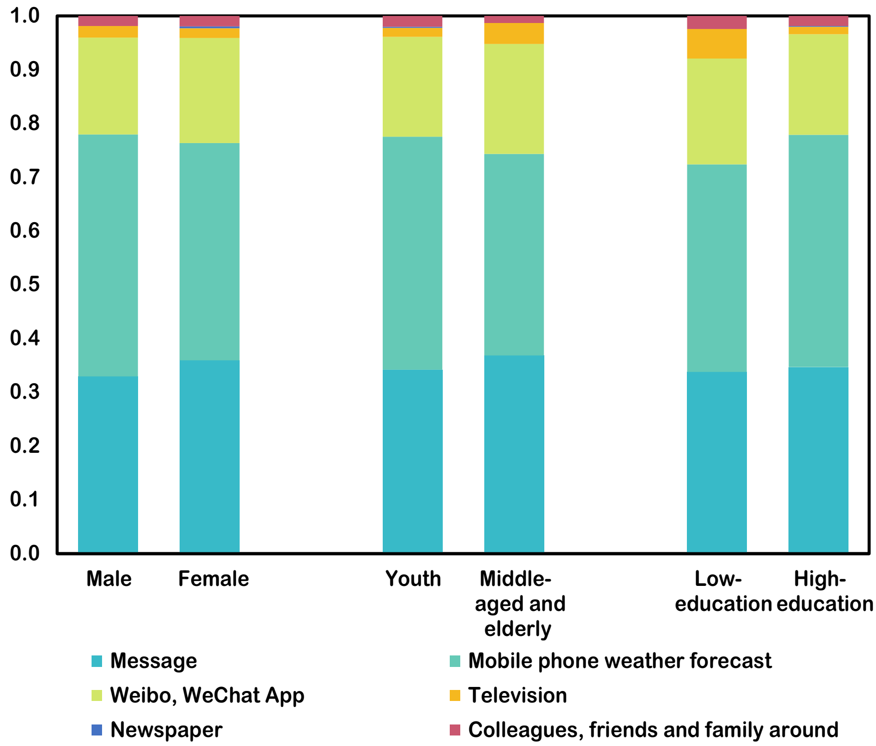

Fig. 5 The main source of warning information.

people who watched TV to receive weather warnings was slightly greater than the proportion of young people. Similarly, the proportion of highly educated people who obtained early warning information from weather forecasts through mobile phones was greater than that of less educated people (Fig. 5). The proportion of respondents who accessed warning information from friends was relatively low. Furthermore, we asked respondents about their views on the population affected by high temperatures and found that 68.5% of the respondents believed that continued high temperatures would affect all people, 10.3% chose to pay attention to outdoor workers, 3.7% considered elderly people and children, 17.2% voted for both outdoor workers and elderly people and children, and only 0.3% of the respondents believed that high temperatures would not affect everyone. The opinions of different groups regarding the people affected by high temperatures were explored through the proportion Z-test. We noted that a greater proportion of women than men reported that all people were affected. A greater proportion of young adults than middle-aged and elderly people believed that all people were affected by high temperatures (Fig. 6). Individuals with higher education levels

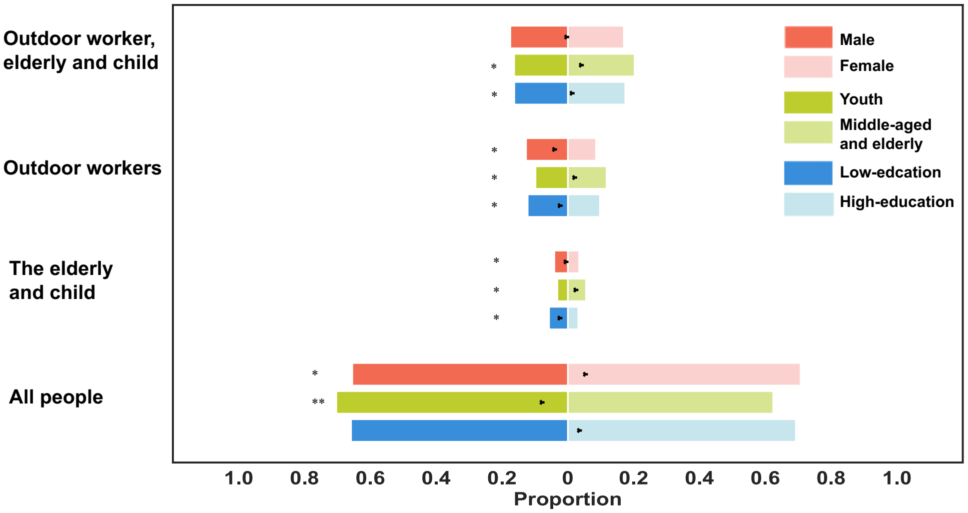

Fig. 6 Opinions on people affected by high temperatures. Note: Symbols *, ** represent the significant differences at $P < 0.05$ and 0.01 levels respectively.

tended to perceive more people as being at risk more than those with lower education levels (Fig. 6).

Discussion

Theoretical significance. To address the gap in the understanding of heat protective behavioural processes, we propose a PMP model to examine decisions about protective behaviours at high temperatures. This study examined the moderating effects of physical and psychological risk perception and the effects of cooling facilities, subsidies, and warnings on protective behaviours during high temperatures. The physical risks associated with heat exposure have been widely documented (Ebi et al. 2021), and our results further support these opinions. Our analyses show that heat-related physical risk modulates psychological risk perception, which might directly influence protective behaviour. Although Yazar et al. (2022) demonstrated that heat-related physical risk magnifies psychological risk perception, that study did not focus on the relationship between physical risk and psychological risk perception. This conclusion effectively fills the above research gap. The analyses suggest that heat exposure influences protective behaviours via physical risk and psychological risk perception. Driven by negative experiences of physical health and higher perception levels, individuals may increase their coping reactions during heat waves. A parallel field study also supported the moderating effects of psychological risk perception between heat exposure and protective behaviours (Ban et al. 2019). The results highlight the role of psychological risk perception in shaping individuals' coping behaviour. Liu et al. (2020) are dubious of the view that psychological risk perception influences protective actions against hazardous chemicals. They suggest that a plausible explanation for this phenomenon is that psychological risk perception is expressed through probability. The perception of psychological risk intensity is not characterized solely by the probability of risk occurrence; rather, it is also influenced by the severity of risk and the apprehension of its potential consequences, which shape individuals' perception of psychological risk. Compared to their studies, we express heat psychological risk perception by probability, severity, and concern, which is more specific and reasonable. These conclusions deepen the mechanism understanding of heat protective behaviours, promote more informed decision-making, and enhance adherence to public health guidelines. According to the IPCC climate risk assessment framework, risk comprises elements of hazard, exposure, and vulnerability; the latter is contingent upon adaptive capacity and susceptibility. The prevailing risk assessment framework pertaining to heat-related challenges has thus far overlooked the critical consideration of individual adaptability. In response, our research endeavours illuminate promising avenues for identifying potential protective behavioural mechanisms. Overall, we envisage the integration of individual adaptation models as an essential augmentation of the risk assessment framework.

Application and implications. As expected, the results highlight the normative roles of public measures in heat protective behaviours during extremely hot weather. Although previous studies differ from our research scope, they have shown that social norms are a key driver of climate action (Doherty et al. 2016) and decisions about flood insurance (Lo, 2013). Public measures influence individuals' judgements of risk information and consequently elicit coping responses (Lo, 2013).

Our results initially demonstrated that appropriate high-temperature subsidies promote traffic protective behaviour, which prevents human health loss due to heat waves. The results highlighted facility measures as significant factors for physical risk and psychological risk perception during hot weather, consistent with the results of Yazar et al. (2022). The significance of facility satisfaction in decreasing physical risk suggests a novel idea for positioning heat protective strategies. Facility satisfaction reflects the sufficiency and effectiveness of infrastructure. The high accessibility, availability, and capacity for the heat mitigation of parks and green spaces are conducive to seeking shelter from heat, triggering urgent requirements for well-established facilities (Zhou et al. 2022).

Furthermore, our research unequivocally substantiates that early warning systems, whether directly or indirectly, empower the public to safeguard themselves against heat-related hazards. The establishment of a heat alerting system before and during persistent hot weather conditions has been recognized as a practical and effective approach to reduce heat-related physical risks (Weinberger et al. 2018). Accurate forecasts can significantly support individuals' and organizations' decision-making. Government organizations must make efforts to provide scientific high-temperature predictions and communicate information broadly to the general public in an accessible way. Emerging artificial intelligence technology has exciting potential for generating accurate predictions of extreme weather events and managing climate-related risk due to the advantages of big data analytics and machine learning algorithms (Radanliev and De Roure, 2022; Singh and Goyal, 2023).

Inadequate knowledge can contribute to low levels of awareness, which leads to insufficient or absent preparedness (Mooney et al. 2020). Elevated levels of psychological risk perception beyond the actual risk give rise to excessive worry and fear, which can potentially trigger mental health issues. Evidence has revealed increased strain on individuals, stress, and anxiety during weather-related shocks (Wahid et al. 2023). Recent research advocates for the provision of online counselling services and mental health care while cautioning against potential risks (Radanliev and De Roure, 2021). Therefore, it is imperative for government entities to convey precise risk information. Our analysis confirmed that the proportion of respondents who accessed warning information through reminders from friends was low. Thus, we recommend that people who are aware of heat risks remind their friends to be vigilant and protect themselves. Traditional communication channels for heat warnings may be ineffective for elderly people; therefore, delivering messages in public spaces frequently visited by older adults is a solution. Since not everyone knows how to protect themselves from harmful health effects, we recommend the provision of detailed health-protective action guidelines during extreme heat periods. We also emphasize the importance of communicating how to protect vulnerable groups such as children, elderly individuals, and outdoor workers. For patients in vulnerable groups, physicians should consciously remind them of high-temperature risks and advise them on behavioural changes. In the future, individuals will have the opportunity to mitigate mental health risks and effectively communicate heat-related risks through a Metaversea, which encompasses diverse and inclusive social environments (Radanliev, 2023).

Conclusions

Understanding how people react to extremely high temperatures can assist policy-makers in effectively implementing intervention strategies. However, driven by a limited understanding of the motivational factors involved in heat-related protective behaviours, this study is the first to propose a model to examine decision-making processes related to protective behaviours during extreme heat. This study provides evidence that heat physical risk and psychological risk perception positively mediate behavioural responses to heat exposure. The indirect effects of heat exposure on outdoor and traffic protective behaviours through physical and psychological risks are greater than the direct effects, and heat exposure directly strongly drives indoor protective behaviour. Physical risk and psychological risk perception are the main factors that influence outdoor heat protective behaviour. Physical risk is the strongest predictor of traffic protective behaviour, and heat exposure contributes the most to indoor protective behaviour. High warning levels are likely to increase individuals' psychological risk perception and inclination to engage in outdoor protective behaviour. Furthermore, high-temperature subsidies significantly facilitate traffic protective behaviour. Our results also support the idea that high facility satisfaction is an important driver of reduced heat physical risk and psychological risk perception.

There are several methodological limitations of this study. The way the samples were collected indicates a bias with regard to education level and age. Future investigations can employ a cross-platform approach to improve the balance of the sample. Furthermore, we adopted a single item for the measurement of warnings and subsidies. Further work could more precisely assess public measures through multiple aspects. Structural equation results are not proof of causality, and future research could test our causal claims with experimental and longitudinal methods. These limitations notwithstanding, our results advance the understanding of individual protective responses and provide substantial evidence for effective behavioural intervention and adaptation policies.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

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References

Ajayi SO, Oyedele LO (2018) Critical design factors for minimising waste in construction projects: a structural equation modelling approach. Resour Conserv Recycl 137:302–313

Azadi Y, Yazdanpanah M, Mahmoudi H (2019) Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. J Environ Manag 250:109456

Ballester J, Quijal-Zamorano M, Turrubiates RFM, Pegenaute F, Herrmann FR, Robine JM, Basagaña X, Tonne C, Antó JM, Achebak H (2023) Heat-related mortality in Europe during the summer of 2022. Nat Med 29:1857–1866

Ban J, Zhou L, Zhang Y, Brooke Anderson G, Li T (2017) The health policy implications of individual adaptive behavior responses to smog pollution in urban China. Environ Int 106:144–152

Ban J, Shi WY, Cui LL, Liu X, Jiang C, Han LY, Wang R, Li TT (2019) Health-risk perception and its mediating effect on protective behavioral adaptation to heat waves. Environ res 172:27–33

Boss SR, Galletta DF, Lowry PB, Moody GD, Polak P (2015) What do systems users have to fear? Using fear appeals to engender threats and fear that motivate protective behaviors in users. MIS Quart 39(4):837–864

Coumou RD (2011) Increase of extreme events in a warming world. Proc Natl Acad Sci USA 108(44):17905–17909

Doane AN, Boothe LG, Pearson MR, Kelley ML (2016) Risky electronic communication behaviors and cyberbullying victimization: An application of Protection Motivation Theory. Comput Hum Behav 60:508–513

Doherty K, Webler L, Thomas N (2016) Social norms and efficacy beliefs drive the Alarmed segment's public-sphere climate actions. Nat Clim Change 6:879–884

Ebi KL, Capon A, Berry P, Broderick C, de Dear R, Havenith G, Honda Y, Kovats RS, Ma W, Malik A, Morris NB, Nybo L, Seneviratne SI, Vanos J, Jay O (2021) Hot weather and heat extremes: health risks. Lancet 398(10301):698–708

Gasparrini A, Guo YM, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B, Leone M, Leone M, De Sario M, Bell M, Guo YL, Wu CF, Kan HD, Yi SM, Coelho SZS, Saldiva PHN, Honda Y, Armstrong B (2015) Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 6736(14):369–375

Gautam B, Rijal HB, Imagawa H, Kayo G, Shukuya M (2020) Investigation on adaptive thermal comfort considering the thermal history of local and migrant peoples living in sub-tropical climate of Nepal. Build Environ 185:107237

Ghansah FA, Chen J, Lu W (2022) Developing a user perception model for smart living: A partial least squares structural equation modelling approach. Build Environ 222:109399

He B-J, Zhao D, Dong X, Xiong K, Feng C, Qi Q, Darko A, Sharifi A, Pathak M (2022) Perception, physiological and psychological impacts, adaptive awareness and knowledge, and climate justice under urban heat: a study in extremely hot-humid Chongqing, China. Sustain Cities Soc 79:103685

Hwong AR, Wang M, Khan H, Chagwedera DN, Grzenda A, Doty B, Benton T, Alpert J, Clarke D, Compton WM (2022) Climate change and mental health research methods, gaps, and priorities: a scoping review. Lancet Planet Health 6(3):e281–e291

Javadi R, Nasrollahi N (2021) Urban green space and health: The role of thermal comfort on the health benefits from the urban green space; a review study. Build Environ 202:108039

Ji JS (2022) Heatwave sears China: Need for actionable climate change adaptation to protect public health. Lancet Regional Health - West Pac 25:100568

Kabisch N, Kraemer R, Masztalerz O, Hemmerling J, Püffel C, Haase D (2021) Impact of summer heat on urban park visitation, perceived health and ecosystem service appreciation. Urban Urban Gree 60:127058

Kim SW, Brown RD (2022) Pedestrians' behavior based on outdoor thermal comfort and micro-scale thermal environments, Austin, TX. Sci Total Environ 808:152143

Lavelle MJ, Rau H, Fahy F (2015) Different shades of green? Unpacking habitual and occasional pro-environmental behavior. Glob Environ Chang 35:368–378

Li J, Sun R, Chen L (2022) Identifying sensitive population associated with summer extreme heat in Beijing. Sustain Cities Soc 83:103925

Liu L, Yan Y, Nazhalati N, Kuerban A, Li J, Huang L (2020) The effect of PM2.5 exposure and risk perception on the mental stress of Nanjing citizens in China. Chemosphere 254:126797

Liu T, Zhang H, Li X, Zhang H (2020) Individual factors influencing risk perceptions of hazardous chemicals in China. Environ Res 186:109523

Lo AY (2013) The role of social norms in climate adaptation: Mediating risk perception and flood insurance purchase. Glob Environ Chang 23(5):1249–1257

Lo AY, Jim CY, Cheung PK, Wong GKL, Cheung LTO (2022) Space poverty driving heat stress vulnerability and the adaptive strategy of visiting urban parks. Cities 127:103740

Ma X, Tian Y, Du M, Hong B, Lin B (2021) How to design comfortable open spaces for the elderly? Implications of their thermal perceptions in an urban park. Sci Total Environ 768:144985

Maddux JE, Rogers RW (1983) Protection motivation and self-efficacy: a revised theory of fear appeals and attitude ahange. J Exp Soc Psychol 19:469–479

Mooney S, McDowell CP, O'Dwyer J, Hynds PD (2020) Knowledge and behavioural interventions to reduce human health risk from private groundwater systems: A global review and pooled analysis based on development status. Sci Total Environ 716:135338

Mooney S, O'Dwyer J, Lavallee S, Hynds PD (2021) Private groundwater contamination and extreme weather events: The role of demographics, experience and cognitive factors on risk perceptions of Irish private well users. Sci Total Environ 784:147118

Morais L, Lopes A, Nogueira P (2021) Human health outcomes at the neighbourhood scale implications: Elderly's heat-related cardiorespiratory mortality and its influencing factors. Sci Total Environ 760:144036

Mouratidis K (2019) Built environment and leisure satisfaction: the role of commute time, social interaction, and active travel. J Transp Geogr 80:102491

Musacchio A, Andrade L, O'Neill E, Re V, O'Dwyer J, Hynds PD (2021) Planning for the health impacts of climate change: flooding, private groundwater contamination and waterborne infection—a cross-sectional study of risk perception, experience and behaviours in the Republic of Ireland. Environ Res 194:110707

Niu J, Xiong J, Qin H, Hu J, Deng J, Han G, Yan J (2022) Influence of thermal comfort of green spaces on physical activity: Empirical study in an urban park in Chongqing, China. Build Environ 219:109168

Radanliev P, De Roure D (2021) Alternative mental health therapies in prolonged lockdowns: narratives from Covid-19. Health technol-ger 11:1101–1107

Radanliev P, De Roure D (2022) Advancing the cybersecurity of the healthcare system with self-optimising and self-adaptative artificial intelligence (part 2). Health Technol 12:923–929

Radanliev P (2023) The Metaverse: Economic and social values and risks of new cryptocurrencies and blockchain technologies Preprints. https://doi.org/10.20944/preprints202304.0100.v1

Ramakreshnan L, Aghamohammadi N, Fong CS, Ghaffarianhoseini A, Wong LP, Noor RM, Hanif NR, Azriyati Wan Abd Aziz WN, Sulaiman NM, Hassan N (2019) A qualitative exploration on the awareness and knowledge of stakeholders towards Urban Heat Island phenomenon in Greater Kuala Lumpur: Critical insights for urban policy implications. Habitat Int 86:28–37

Rogers RW (1975) Protection motivation theory of fear appeals and attitude-change. J Psychol 91:93–114

Romanello M, Napoli CDGreen C, et al.(2023) Lancet 402(10419):2346–2394

Rufat S, Botzen WJW (2022) Drivers and dimensions of flood risk perceptions: Revealing an implicit selection bias and lessons for communication policies. Glob Environ Chang 73:102465

Shi J, Cui L, Ma Y, Du H, Wen K (2018) Trends in temperature extremes and their association with circulation patterns in China during 1961–2015. Atmos Res 212:259–272

Shih W-Y, Lung S-CC, Hu S-C (2022) Perceived heat impacts and adaptive behaviours in different socio-demographic groups in the subtropics. Int J Disast Risk Re 71:102799

Sinclair AH, Hakimi S, Stanley ML, Adcock RA, Samanez-Larkin GR (2021) Pairing facts with imagined consequences improves pandemic-related risk perception. Proc Natl Acad Sci USA 118(32):e2100970118

Singh S, Goyal MK (2023) Enhancing climate resilience in businesses: The role of artificial intelligence. J Clean Prod 418:138228

Slovic (1987) Perception of risk. Science 236(4799):280

Son J-Y, Choi HM, Miranda ML, Bell ML (2022) Exposure to heat during pregnancy and preterm birth in North Carolina: Main effect and disparities by residential greenness, urbanicity, and socioeconomic status. Environ Res 204:112315

Sun X-B, Ren G-Y, Shrestha AB, Ren Y-Y, You Q-L, Zhan Y-J, Xu Y, Rajbhandari R (2017) Changes in extreme temperature events over the Hindu Kush Himalaya during 1961–2015. Adv Clim Chang Res 8(3):157–165

Tang Z, Miller AS, Zhou Z, Warkentin M (2021) Does government social media promote users' information security behavior towards COVID-19 scams? Cultivation effects and protective motivations. Gov Inf Q 38(2):101572

Vaidyanathan A, Saha S, Vicedo-Cabrera AM, Gasparrini A, Abdurehman N, Jordan R, Hawkins M, Hess J, Elixhauser A (2019) Assessment of extreme heat and hospitalizations to inform early warning systems. PNAS 116(12):5420–5427

Veitch J, Ball K, Rivera E, Loh V, Deforche B, Best K, Timperio A (2022) What entices older adults to parks? Identification of park features that encourage park visitation, physical activity, and social interaction. Landsc Urban Plan 217:104254

Wahid SS, Raza WA, Mahmud I, Kohrt BA (2023) Climate-related shocks and other stressors associated with depression and anxiety in Bangladesh: a nationally representative panel study. Lancet Planet Health 7:e137–e146

Wang P, Zhou B, Han L, Mei R (2021) The motivation and factors influencing visits to small urban parks in Shanghai, China. Urban Urban Gree 60:127086

Wang Y, Wang A, Zhai J, Tao H, Jiang T, Su B, Yang J, Wang G, Liu Q, Gao C, Kundzewicz ZW, Zhan M, Feng Z, Fischer T (2019) Tens of thousands additional deaths annually in cities of China between 1.5 °C and 2.0 °C warming. Nat Commun 10:1–7

Weinberger KR, Zanobetti A, Schwartz J, Wellenius GA (2018) Effectiveness of National Weather Service heat alerts in preventing mortality in 20 US cities. Environ Int 116:30–38

Yang J, Gao Q, Liu M, Wang Q, Ding Z, Liu M, Bi J (2022) Using laboratory experiment to inform local adaptation policies for extreme heat events. Environ Sci Policy 136:216–224

Yazar M, York A, Larson KL (2022) Adaptation, exposure, and politics: local extreme heat and global climate change risk perceptions in the phoenix metropolitan region, USA. Cities 127:103763

Zaval L, Keenan EA, Johnson EJ, Weber EU (2014) How warm days increase belief in global warming. Nat Clim Change 4:143–147

Zhao P, Zhu N, Chong D, Hou Y (2022) Developing a new heat strain evaluation index to classify and predict human thermal risk in hot and humid environments. Sustain Cities Soc 76:103440

Zhao YJ, Huang Z, Wang SY, Hu JX, Xiao JP, Li X, Liu T, Zeng WL, Guo LC, Du QF, Ma WJ (2019) Morbidity burden of respiratory diseases attributable to ambient temperature: a case study in a subtropical city in China. Environ Health 18:89

Zheng S, Yu L (2022) The government's subsidy strategy of carbon-sink fishery based on evolutionary game. Energy 254:124282

Zhou C, An Y, Zhao J, Xue Y, Fu L (2022) How do mini-parks serve in groups? A visit analysis of mini-park groups in the neighbourhoods of Nanjing. Cities 129:103804

Zhou Y, He Z, Zhao S (2021) How do government subsidies affect the strategic choices of enterprises and individuals in agricultural waste recycling? Sustain Prod Consum 28:1687–1698

Zhou Z, Liu J, Zeng H, Zhang T, Chen X (2020) How does soil pollution risk perception affect farmers' pro-environmental behavior? The role of income level. J Environ Manag 270:110806

Zhu W, Wei J, Zhao D (2016) Anti-nuclear behavioral intentions: the role of perceived knowledge, information processing, and risk perception. Energ Policy 88:168–177

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Author contributions

All authors contributed to the design and execution of this project and reviewed and edited the manuscript. S.R.H. supervised the project and edited this paper. L.J.Y. conducted the initial constructs, analysed the output data and wrote the original draft.

Competing interests

The authors declare no competing interests.

Ethical approval

This study did not include medical research or human experimentation, as stated in the Declaration of Helsinki. Informed consent was obtained from all participants before the survey. Additionally, the investigation was strictly anonymous, and the collected information was used only for research purposes. Therefore, the Ethics Committee of the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences deemed the questionnaire and methodology for this study to be exempt from ethical review (without an approval number).

Informed consent

Informed consent was obtained from all individual participants included in the study.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-024-02790-3.

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