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Integrating new indicators of predictors that shape the public's perception of local extreme temperature in China

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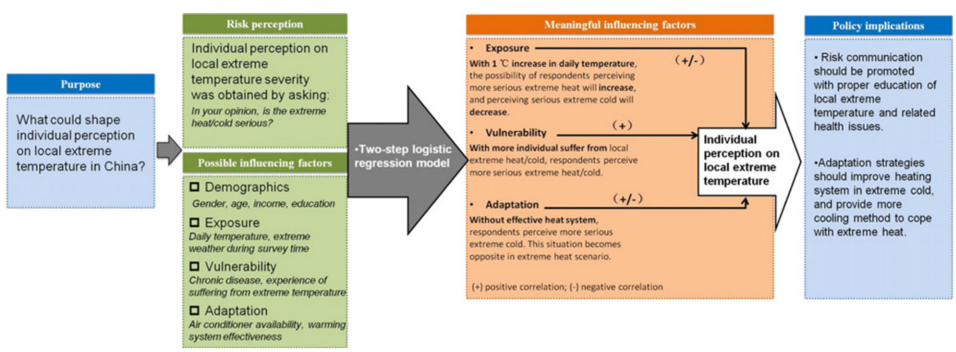
HIGHLIGHTS

- First study of risk perception on both local extreme heat and cold in China
- Exposure, vulnerability and adaption significantly affect extreme weather perception.
- Frequent local extreme weather may arouse more perception on related health issues.

GRAPHICAL ABSTRACT



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ABSTRACT

The public's risk perception of local extreme heat or cold plays a critical role in community health and prevention under climate change. However, there is limited evidence on such issues in China where extreme weather is occurring more frequently due to climate change. Here, a total of 2500 residents were selected using a three-step sampling method and investigated by a questionnaire in two representative cities. We investigated risk perception of extreme heat in Beijing and extreme cold in Harbin in 2013, aiming to examine their possible correlations with multiple epidemiological factors. We found that exposure, vulnerability, and adaptive ability were significant predictors in shaping public risk perceptions of local extreme temperature. In particular, a 1 °C increase in daily temperature resulted in an increased odds of perceiving serious extreme heat in Beijing (OR = 1.091; 95% CI: 1.032, 1.153), while a 1 °C increase in daily temperature resulted in a decreased odds of perceiving serious extreme cold in Harbin (OR = 0.965; 95% CI: 0.939, 0.992). Therefore for both extreme heat and cold, frequent local extreme temperature exposure may amplify a stronger communication. Health interventions for extreme temperature should consider exposure, vulnerability, and adaptive ability factors. This will help improve the public's perception of climatic changes and their willingness to balance adaption and mitigation appropriately.

1. Introduction

Risk perception of local extreme temperature perception is a psychological measure of an individual's extreme weather beliefs and behavior orientation (Howe et al., 2013). The goal of improving

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individual awareness of self-protection and exposure behaviors under extreme temperatures events could be achieved by engaging wide risk perceptions on local temperature changes (Brouwer and Schaafsma, 2012; Liu et al., 2013; Carlton et al., 2015). However, trends of local extreme heat or cold temperature perception and its potential impact factors are not fully understood, particularly in developing countries such as China with its large source of emissions, high frequency of serious extreme temperature events, and high level of vulnerability. As the negative effects of climate change worsens, regional extreme heat and cold temperatures in most areas of China are increasing in both frequency and strength during the past hundred years (1909–2011) (Committee Of National Assessment Report On Climate Change, 2015), resulting in health impacts, including increased mortality and morbidity (Hijioka et al., 2014). Previous studies reported that people could increase awareness to climate change with personal experience to local extreme temperatures (Vitek and Berta, 1982; Howe et al., 2013; Liu et al., 2013), therefore the Chinese public perception of extreme heat and cold temperatures may already be magnified (Tian et al., 2011; Wei et al., 2014). Since promoting and regulating public health and adaptation policy require the understanding of the ways in which individuals perceive and respond to extreme temperature related risk (Haque et al., 2012; Howe et al., 2013; Nitschke et al., 2013; Wei et al., 2014), there is a great need to understand how the Chinese public interpret local extreme heat and cold temperatures (Egan and Mullin, 2014; Wolf et al., 2010).

Risk perception of extreme heat and cold temperature could be influenced by multi-faceted factors (Lindell and Hwang, 2008). There is considerable evidence that confirms the importance of demographic characteristics (Haque et al., 2012; Semenza et al., 2008; Wolf et al., 2010), previous personal experience of extremes (Spence et al., 2011; Howe et al., 2013; Liu et al., 2013), amount of information given, and exposure to extreme temperatures in affecting extreme heat and cold temperature perception in individuals of developed countries (Lindell and Hwang, 2008; Liu et al., 2013; Wachinger et al., 2013; Wei et al., 2014). An Australian study suggested that age, household income, living arrangement, and fan ownership were significant predictors of perception on extreme heat related health risk (Akompab et al., 2013), and these factors also have had impacts on extreme heat awareness in New York City (Lane et al., 2013). In Europe, previous personal experience of extreme weather events, such as flood (Spence et al., 2011) and extreme cold temperatures (Capstick and Pidgeon, 2014; Wolf et al., 2010) could significantly impact public recognition on and against climate change. However, these findings may not describe the whole picture of extreme temperature perception sufficiently in developing countries, where residents are more vulnerable to adverse impacts of extreme weather. An epidemiologic study found that multiple climatic and social factors could explain the heterogeneity in temperature-related health effects (Hajat and Kosatky, 2010; Huang et al., 2013a) such as the exposure to extreme temperatures, vulnerable living situations, and adaptive ability such as using air conditioners (ACs) or heating systems. However, the potential impacts of these factors on extreme temperature perception have not been examined. In addition, most previous studies focused on extreme heat perception under the "global warming" context (Capstick and Pidgeon, 2014), while the awareness of extreme cold changes were seldom discussed.

Extreme temperature-related health risk perception were also ineffectively discussed even when the health effect caused by temperature anomalies worsened (Bauchner and Fontanarosa, 2014; Patz et al., 2014). As mean global temperature continues to rise (Stocker et al., 2014), critical aspects including demographic characteristics, individual exposure to extreme changes, vulnerability, and adaptive ability may also change (Kinney et al., 2008). Therefore, predicting extreme temperature perception with these factors should be necessary in order to develop adaptive strategies coping with future changes.

Here, we simultaneously examined extreme heat and extreme cold temperature perception with respect to multiple epidemiological indicators. We conducted a study of large magnitude focusing on both extreme heat and cold temperatures simultaneously in the country. We did so because we aimed to obtain a whole picture and a complete analysis of Chinese public risk perception on local extreme temperatures. We also increased the relevance of our research by including two climatic contrasting large cities in which people are exposed to different ranges of temperatures. In addition, we surveyed the risk perception on the severity of extreme temperature events (heat wave, cold spell) as well as the severity of related health risk. We hypothesized that the individual perception of extreme temperatures corresponds with exposure, vulnerability, and adaptive ability in both extreme heat and cold scenarios. To test our hypotheses, we examined the relationship between risk perception of extreme temperatures and demographics, exposure, vulnerability, and adaptation. We then discuss the policy implications of our findings.

2. Method

2.1. Study area

Based on recent local extreme temperature data and available demographic data, we developed a face-to-face questionnaire survey and piloted it in Beijing in July 2013 and in Harbin from December 2012 to January 2013. These two cities are located in different climatic region of China (see Fig. S1). Beijing has a typical temperate semi-humid continental monsoon climate, with an annual average temperature of around 12.8 °C and summer (June to August) average temperature of 23.8–27.4 °C. Harbin is one of the coldest metropolis in China, with an annual average temperature of around 4.3 °C and winter (November to the following March) average temperature ranges between −7.4 ~ −21.1 °C. Beijing is a microcosm of rapid urbanization in China, where naturally high temperatures are being compounded by a pronounced urban heat island effect, which exacerbates the adverse influence in this city. Harbin is the capital city of Heilongjiang Province and also an important city for economy and education in Northeast China. Since serious extreme heat days occur frequently and affect human health in Beijing in recent years (Li et al., 2015) and extreme cold days occur frequently in Harbin (Committee of National Assessment Report on Climate Change, 2015), the two cities are well suited to study public risk perceptions of local extreme temperatures .

2.2. Sampling method

A three-step sampling method was adopted as follows for Beijing and Harbin. We first selected several sample units (communities) based on probabilities proportional to population size (PPS). In this study, a community is a cluster of about 1500 to 5000 households located in same area. Second, households were selected within each sample units using simple random sampling (SRS). Third, the KISH table, a widely used method to select members within a household to be interviewed (Kish, 1949), was applied to select one person in each home, and a structured and anonymous interview was arranged for the selected person at home. In places without detailed population information, simple random sampling was adopted. The selected person should be over 16 years old and has been living in the city for at least one year. Research groups from Beijing CDC and Harbin CDC attended an intensive training session and were deployed to conduct the survey. There were 30 trained researchers involved in the interview in Beijing and 20 trained researchers in Harbin. The interviews were conducted at home using a paper questionnaire written in Chinese. Each interview took about 15 min. The surveys were approved by the Ethics Committee of China CDC and Harbin CDC. Written informed consent was obtained from all participants.

In Beijing and Harbin, 1500 and 1000 respondents were included respectively. Excluding incomplete questionnaires and those with missing value and logical error, valid responses were obtained from 1229 Beijing residents and 891 Harbin residents, with an effective response rate of 81.9% (1229/1500) and 89.1% (891/1000) respectively. Sample structures in two cities were presented in Table 1, in comparison to the local population structure in parentheses (local income information unavailable due to data limitation). The Beijing sample was well matched with the local population structures in gender and education, while the respondents were slightly younger than the average age of the city population. There was sampling bias indicating more females and higher education respondents in Harbin. This pattern was also found by Huang et al. (2013b). This might be attributed to the fact that older, uneducated people are more likely to have difficulty understanding survey questions and cannot complete a questionnaire easily (Huang et al., 2013b). Furthermore, females are more likely to stay at home during the survey time.

2.3. The questionnaire

At the beginning of the questionnaire, a paragraph describing background information about local extreme heat in Beijing and extreme cold in Harbin, which was basic introduction including definition of extreme heat or cold, the recent local weather condition, and possible health effect, was provided to ensure the respondents have a basic sense of local extreme heat or cold as well as a better understanding of the questionnaire. This allows us to obtain more effective responses in the field survey.

The core of the questionnaire was adapted based on the psychometric paradigm method, which measures individual preference of different risks by asking them directly using the questionnaire (Siegrist et al., 2005; Slovic, 1987; Tam and McDaniels, 2013). Perceptions of the severity of local extreme heat/cold temperature and its related health risk were assessed using the questions "In your opinion, is the risk related to heat wave/cold spell serious during 2010 to 2013?" and "In your opinion, is the health risk associated with the heat wave/cold spell serious to yourself?". Public risk perception was measured using a five point scale ranging from 1 (not serious at all) to 5 (very serious) to estimate the extent of people's perceptions. Respondents were asked to provide a score between 1 and 5 for each specific question to capture the full range of responses. This is unlike previous studies (Howe et al., 2013; Spence et al., 2011), in which individuals were just asked whether they could perceive climate change or not.

At the end of questionnaire, questions for three different categories of possible explanatory factors (demographics, individual vulnerability, and adaptation to extreme temperature changes) were included, as explained in Table 2. Respondents were asked to fill each question according to their current and real situation (*e.g.* age, gender, education year, income level, air conditioner/heat system usage, chronic diseases, and self-report suffering experience of extremes).

It's worth noting that in this study we defined a vulnerable group as a group with more possibility of being impacted and suffered from extreme temperature change. Chronic disease and self-reported suffering experience from extreme heat or cold were two typical factors. Because chronic disease is in keeping with the idea of a sensitive population, while self-reported extreme heat or cold here should increase the probability that the respondents had experienced or could experience health impact from extreme temperature. It is the individual's subjective judgment of whether they suffered during extremes or not based on their own experience, physical situation, and surrounding environment (Slovic, 1987). Respondents who once suffered from extreme heat or cold may indicate they are more easily to be impacted. Therefore, self-reported suffering experience is not a real exposure factor but rather a vulnerability factor due to the hypothesis that vulnerable populations may be more likely to suffer from extremes.

Table 1
The sample structure in two surveys[a].

	Beijing	Harbin
Gender		
Male	47.8% (52.0%)	35.8% (51.0%)
Female	52.2% (48.0%)	64.2% (49.0%)
Age (years)		
16–29	20.6% (31.2%)	20.2% (28.2%)
30–59	53.8% (53.6%)	65.1% (57.4%)
≥60	25.6% (15.2%)	14.7% (14.4%)
Education (years)		
≤6	11.6% (12.0%)	6.6% (25.0%)
7–12	55.7% (55.0%)	46.6% (60.0%)
>12	32.7% (33.0%)	46.8% (15.0%)
Income (RMB, yuan)		
<2000	18.2%	23.8%
<8000	59.9%	63.8%
>8000	21.9%	12.4%
Respondents access to AC	82.5%	NA
Respondents access to effective heating system	NA	72.3%
Respondents with chronic diseases	26.2%	78.9%
Respondents with suffering experience from extreme heat	57.8%	NA
Respondents with suffering experience from extreme cold	NA	37.6%
Number of extreme days	Extreme heat	Extreme cold
2010	15	14
2011	6	11
2012	6	13
2013	13	14

[a] The local population structure were presented in the parentheses.

2.4. Temperature data

Unlike demographic, vulnerability, and adaptation variables, the factor of individual exposure (temperature data) was not obtained from questionnaires. Complete temperature dataset covering the period between 1984 and 2013 (30-year data) for each city was acquired from the National Climatic Data Center (NCDC, http://www7.ncdc.noaa.gov), which provides daily temperature of Beijing from the station in urban areas (Station No. 54,511, E 116.47°, N 39.8°) and that of Harbin from an urban station (Station No.50953, E 126.77°, N 45.75°). The quality of the dataset was good, with only 0.15% of total days missing in Beijing (16 missing values) and 0.05% of total days missing in Harbin (5 missing values). Days with missing weather data were excluded from the analysis. Daily mean temperature from the dataset was included in this study, which was used to measure two exposure variables: (1) daily mean temperature on the survey day; (2) whether there were extreme heat/cold days within latest 7 days before the survey date. In order to depict the historical trends of extreme temperature, the annual average temperature of hot months (June to August) in Beijing and the annual average temperature of cold months (November to February) in Harbin during 1984–2013 were calculated and presented in Fig. S2. The figure shows a strong trend of temperature increasing over time in both Beijing and Harbin, which has been found and accepted by the academic society of climate change, and our findings reaffirm this conclusion. It is helpful to explain the extreme heat weather in Beijing. Nevertheless, extreme cold weather can occur in Harbin even with an increased average temperature. Therefore, we present Fig. S3 to show the annual number of extreme heat days in Beijing and extreme cold days in Harbin from 1984 to 2013, which indicated a higher frequency of extreme weather in both Beijing and Harbin in 2013 relative to previous years.

To define extreme heat and extreme cold, 30-year historical data sets for each site were used to calculate the 97.5th percentile (28.8 °C) as the threshold temperature for extreme heat in Beijing, and the 2.5th percentile (−21.7 °C) as the threshold extreme cold temperature in Harbin. An extreme heat day was defined as a temperature above the 97.5th

Table 2
Description of the variables for both extreme heat and extreme cold risk perceptions.

Category	Variables	Applied scenarios	Description
Dependent variables	Extreme heat/cold temperature severity (Y1)	Both	5-point scale variable, representing the risk perception on severity of heat wave (cold spell); (1 = not serious at all; 5 = very serious).
	Related health risk severity (Y2)	Both	5-point scale variable, representing the risk perception on severity of heat wave (cold spell) related health; (1 = not serious at all; 5 = very serious).
Demographic variables	Gender	Both	Dichotomous variable, representing the gender of the respondents; (male = 1; female = 0).
	Age	Both	Continuous variable, representing the age of the respondents (year).
	Education	Both	Categorical variable, representing the educational level of the respondents; (below 6 years = 1; 6–12 years = 2; above 12 years = 3).
	Income	Both	Categorical variable, representing the annual income of the family (RMB/yr); (<2000 RMB = 1; <8000 RMB = 2; >8000 RMB = 3).
Exposure variables	Daily temperature	Both	Continuous variable, representing the mean temperature of the survey day (°C)
	Extreme heat days in last 7 days[a]	Extreme heat	Dichotomous variable, representing whether there are extreme days (temperature above 28.8 °C) during the last 7 days before the survey; (There is at least one high temperature day = 1; there are no high temperature days = 2).
	Extreme cold days in last 7 days[b]	Extreme cold	Dichotomous variable, representing whether there are extreme days (temperature below −21.7 °C) during the last 7 days before the survey; (There is at least one low temperature day = 1; there are no low temperature days = 2).
Vulnerability variables	Extreme heat experience	Extreme heat	Categorical variable representing self-reported extreme heat temperature experience of the respondents;(experienced extreme heat temperature since 2010 = 1; experienced extreme heat temperature and health damage = 2; never experienced extreme heat temperature since 2010 = 3).
	Extreme cold experience	Extreme cold	Categorical variable representing self-reported extreme cold temperature experience of the respondents;(experienced extreme cold temperature since 2010 = 1; experienced extreme cold temperature and health damage = 2; never experienced extreme cold temperature since 2010 = 3).
	Chronic disease	Both	Dichotomous variable, representing whether the respondents have chronic diseases; (with chronic disease = 1; without chronic disease = 2).
Adaptive variables	AC availability	Extreme heat	Dichotomous variable, representing whether the respondents use air conditioner in their house; (without air conditioner = 0; with air conditioner = 1).
	Effectiveness of heat system	Extreme cold	Dichotomous variable, representing whether the respondents have effective heat system in their house; (without effective heat system = 0; with effective heat system = 1).

[a] 28.8 °C is the 97.5th percentile daily maximum temperature during the last 30 years in Beijing.
[b] −21.7 °C is the 2.5th percentile daily minimum temperature during the last 30 years in Harbin.

percentile in Beijing, whereas an extreme cold day was defined as a temperature below the 2.5th percentile in Harbin (Meehl and Tebaldi, 2004; Gasparrini et al., 2015). The numbers of extreme days from 2010 to 2013 in each city are shown in Table 1. Furthermore, the survey date was also included in this study so that we could obtain the actual temperature data of each day. This way, we obtained daily temperature and the variable of extreme days within the latest 7 days during survey period.

2.5. Statistical models

The data from the two cities were analyzed separately. Average levels of extreme heat and cold temperature perception are presented in Table S1. To analyze the factors that influence public risk perception in each city, we performed non-parametric tests to examine the differences between the different groups' perception (Table S2). Significance was set at the 0.05 level.

To examine influences on risk perception of extreme heat/cold severity at the individual level of demographics, exposure, vulnerable, and adaptive variables, we constructed two ordinal logistic regression models for each city. One model used extreme temperature severity perception as a dependent variable, and another model used related health risk severity perception as a dependent variable. In these models, severity perception variables were 5-point scale variables. In the predictor variables listed in Table 2, age and daily mean temperature were continuous variables; others were treated as dichotomous or categorical variables. Two-step regression analysis was then conducted for each model. In the first step only demographic factors were used as independent variables in both models. In the second step we added exposure, vulnerability, and adaptive factors as independent variables to indicate

Table 3
The results of an ordinal logistic model analyzing the demographic factors predicting the perceived severity of extreme temperature and related health risk.

	Beijing		Harbin	
	Extreme heat severity	Heat-related health risk severity	Extreme cold severity	Cold-related health risk severity
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Demographic factors				
Gender_0 *vs.* gender_1[a]	0.956 (0.774, 1.181)	1. 095 (0.889, 1.348)	1.062 (0.822, 1.372)	0.981 (0.761, 1.265)
Age	1.000 (0.999, 1.002)	1.001 (0.999, 1.002)	1.007 (0.996, 1.018)	1.000 (0.989, 1.011)
Edu_1 *vs.*edu_3[b]	**0.545 (0.373, 0.796)**	**0.623 (0.430, 0.902)**	0.872 (0.511, 1.490)	1.326 (0.781, 2.253)
Edu_2 *vs.*edu_3	**0.618 (0.488, 0.784)**	**0.629 (0.499, 0.794)**	**0.736 (0.559, 0.969)**	0.999 (0.761, 1.311)
Inc_1 *vs.*inc_3[c]	1.433 (0.762, 2.696)	1.166 (0.628, 2.164)	1.161 (0.756, 1.783)	1.050 (0.685, 1.610)
Inc_2 *vs.*inc_3	1.277 (0.709, 2.298)	0.909 (0.512, 1.616)	1.340 (0.917, 1.958)	0.977 (0.670, 1.424)
Nagelkerke R^2	0.017	0.016	0.010	0.011

Significant results were shown in bold font.
[a] Group of male was treated as gender_1.
[b] Group of education > 12 years was treated as edu_3.
[c] Group of Income >8000 yuan (RMB) was treated as inc_3.

their estimated effects on both perceptions. Odds ratios (ORs) are presented to show the effects from different factors.

To reduce the uncertainty from model selections, we also provided binary logistic regression results in the supplementary file (see Table S3 and Table S4). SPSS 18.0 was used for all data analyses.

3. Results

The results of the first step model present only the effects of the demographic variables (Table 3), which were treated as typical factors that influence risk perception in the research literature (Slovic, 1987; Wachinger et al., 2013). Results show that only education level had significant effects on both extreme heat severity and extreme cold severity. The odds of individuals with low level (edu_1, OR = 0.545; 95% CI: 0.373, 0.769) and middle level (edu_2, OR = 0.618; 95% CI: 0.488, 0.784) perceiving serious extreme heat temperature and related health risk were 54.5% ~ 62.9% of the odds of those with high education level (edu_3). For extreme cold severity perception, the odds of perceiving serious extreme cold temperature for respondents with middle education level was 73.6% of the odds of those with high education level.

Compared to the results in first step model, the effect of demographics was attenuated in the second step model. Exposure, vulnerability, and adaptive variables were more significant predictors of the risk perception of extreme temperature severity and related health risks in both scenarios. For exposure factors, with a 1 °C increase in daily temperature, the odds of perceiving serious extreme heat in Beijing increased (OR = 1.091; 95% CI:1.032.1.153), whereas the odds of perceiving serious extreme cold decreased (OR = 0.965; 95% CI: 0.939, 0.992) when daily temperature increased 1 °C in Harbin (see Table 4). ORs indicated that both perceived severity of heat wave and cold spell were significantly influenced by ambient temperature changes (Fig. 1). Individuals experiencing extreme heat days in the last 7 days before survey day had a higher odds of perceiving the severity of extreme heat (OR = 2.028; 95% CI: 1.557, 2.643) (Table 4). Fig. 2 presents the effect on perceived severity from extreme temperature days in both extreme heat and cold scenarios. For vulnerability factors, the suffering experience of self-reported extreme heat and cold had positive effects on risk perception: the odds of perceiving extreme heat severity could increase by >40%(OR = 1.446; 95% CI:1.108,1.887), and that of extreme cold-related risk severity perception could increase by >70% (OR = 1.773; 95% CI:1.074,2.926). Residents with poor health status presented higher odds to perceive extreme temperature severity. In adaptive factors, a comparison of groups without AC revealed the opposite effects in adaptive factors, including a negative effect on heat-related health risk perception (OR = 0.682; 95% CI: 0.505, 0.921); while the group without a heating system indicated a higher odds of perceiving serious extreme cold (OR = 1.349; 95% CI: 1.017, 1.789) as well as related health risks (OR = 1.514; 95% CI:

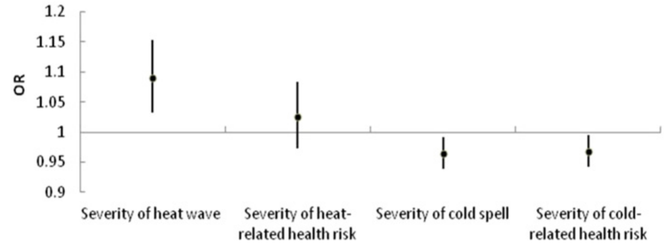

Fig. 1. The estimated effects of daily temperature on risk perception of extreme heat/cold and related health risks. Perceived severity of heat wave will significantly increase with 1 °C increase in daily temperature; while perceived severity of cold spell and cold-related health risk will decrease with 1 °C increase in daily temperature.

Table 4
The results of an ordinal logistic model analyzing the multi-angle factors predicting the perceived severity of extreme temperature and related health risk.

	Beijing		Harbin	
	Extreme heat severity OR (95% CI)	Heat-related health risk severity OR (95% CI)	Extreme cold severity OR (95% CI)	Cold-related health risk severity OR (95% CI)
Demographic factors				
Gender_0 *vs.* gender_1	0.929 (0.750, 1.150)	1.049 (0.850, 1.294)	1.067 (0.825, 1.379)	0.982 (0.7615, 1.267)
Age	1.000 (0.998, 1.002)	1.000 (0.998, 1.002)	0.999 (0.987, 1.011)	0.999 (0.987, 1.011)
Edu_1 *vs.*edu_3	**0.516 (0.346, 0.769)**	**0.603 (0.408, 0.891)**	0.810 (0.471, 1.395)	1.205 (0.704, 2.064)
Edu_2 *vs.* edu_3	**0.607 (0.475, 0.774)**	**0.629 (0.495, 0.779)**	0.784 (0.593, 1.036)	1.042 (0.791, 1.373)
Inc_1 *vs.*inc_3	1.397 (0.725, 2.692)	1.557 (0.819, 2.960)	1.056 (0.686, 1.627)	0.989 (0.644, 1.520)
Inc_2 *vs.*inc_3	1.314 (0.724, 2.385)	1.041 (0.581, 1.866)	1.269 (0.864, 1.868)	0.936 (0.638, 1.372)
Exposure factors				
Daily temperature	**1. 091 (1.032, 1.153)**	1.026 (0.973, 1.083)	**0.965 (0.939, 0.992)**	**0.968 (0.942,0.995)**
Heat day in last 7 days_1 *vs.* heat day in last 7 days_2[a]	**2. 028 (1.557, 2.643)**	1.228 (0.950, 1.589)	/	/
Cold day in last 7 days_1 *vs.* cold day in last 7 days_2[b]	NA	NA	1.086 (0.586, 2.013)	1.043 (0.564, 1.930)
Vulnerable factors				
Heat-wave experience_1 *vs.* heat-wave experience_3[c]	**1.446 (1.108, 1.887)**	1.145 (0.882, 1.488)	NA	NA
Heat-wave experience_2 *vs.* heat-wave experience_3	**1.909 (1.475, 2.470)**	**2.418 (1.874, 3.119)**	NA	NA
Cold spell experience_1 *vs.* cold spell experience_3[d]	NA	NA	1.110 (0.819, 1.506)	1.193 (0.883, 1.613)
Cold spell experience_2 *vs.* cold spell experience_3	NA	NA	1.277 (0.769, 2.123)	**1.773 (1.074, 2.926)**
Chronic disease_1 *vs.* chronic disease_2[e]	1.267 (0.983, 1.635)	**1.381 (1.075, 1.773)**	**1.811 (1.296, 2.529)**	1.218 (0.876, 1.790)
Adaptive factors				
AC available_0 *vs.* AC available _1[f]	0.933 (0.688, 1.266)	**0.682 (0.505, 0.921)**	NA	NA
Heat system effectiveness_0 *vs.* heat system effectiveness_1[g]	NA	NA	**1.349 (1.017, 1.789)**	**1.514 (1.145, 2.003)**
Nagelkerke R^2	0.075	0.081	0.043	0.031

Significant results were shown in bold font.
[a] Group of 'there are high temperature days' was treated as Heat day in last 7 days_1, 'there are no high temperature days' was treated as Heat day in last 7 days_2.
[b] Group of 'there are low temperature days' was treated as Cold day in last 7 days_1, 'there are no low temperature days' was treated as Cold day in last 7 days_2.
[c] Group of 'never experienced extreme heat temperature since 2010' was treated as Heat-wave experience _3, 'experienced extreme heat temperature since 2010' was treated as Heat-wave experience_1, 'experienced extreme heat temperature and health damage' was treated as Heat-wave experience_2.
[d] Group of 'never experienced extreme cold temperature since 2010' was treated as Cold-spell experience _3, 'experienced extreme cold temperature since 2010' was treated as Cold spell experience_1, 'experienced extreme cold temperature and health damage' was treated as Cold spell experience_2.
[e] Group of 'with chronic disease' was treated as Chronic disease_1, 'without chronic disease' was treated as Chronic disease_2.
[f] Group of 'without air conditioner' was treated as AC available_0, 'with air conditioner' was treated as AC available_1.
[g] Group of 'without effective heat system' was treated as Heat system effectiveness_0, 'with effective heat system' was treated as Heat system effectiveness_1.

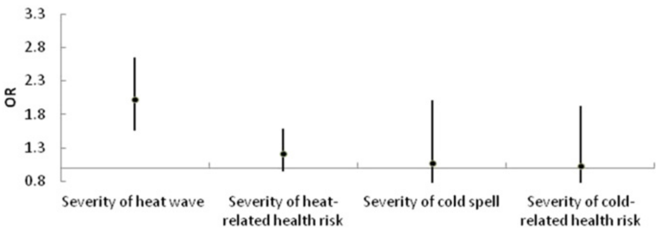

Fig. 2. The estimated effects of extreme days during the last 7 days before the survey on risk perception of extreme heat/cold and related health risks. Perceived severity of heat wave will significantly increase when there were extreme heat days occurred during the last 7 days.

1.145, 2.063). Overall, exposure, vulnerability, and adaptive ability could account for most of the variation in the public risk perception of extreme temperature and the related risk severity (see Table 4).

Results of sensitivity analyses adopting binary logistic regression models were similar to the ordinal model outcomes (see Table S3, S4).

4. Discussion

Based on a comparison of the two-step models, the effects of epidemiological factors could explain more variation in the public risk perception on the severity of extreme temperatures and the related health risk than demographic factors for both the extreme heat and extreme cold scenarios. Since the effects of exposure, vulnerability, and adaptive factors on risk perception were rarely addressed simultaneously, this study design is very important for the public risk perception of extreme temperature in China.

Only education level presented a significant effect on perception among the demographic aspects. Highly educated groups had a higher possibility of perceiving more extreme temperature and related health risk severity than those groups with a lower level of education. Recent studies revealed that extreme temperatures and their related health risks (Stocker et al., 2014; Hijioka et al., 2014) are emerging problems and are difficult to perceive as dangerous issues; therefore, they are easily neglected (Howe et al., 2013; Spence et al., 2011). Most individuals do not perceive extreme temperatures as a direct personal risk but rather as a remote threat in the far future (DeBono et al., 2012; Leiserowitz, 2006). A higher education level might provide individuals with more knowledge about specific hazards (Agusomu and Paki, 2011; Ding et al., 2011; Myers et al., 2013), which helps individuals increase their understanding of extreme temperature and its negative effects on human health, ultimately leading to a higher perception of extreme heat/cold severity (Agusomu and Paki, 2011; Akerlof et al., 2010). Therefore, formal education of extreme heat and cold should be promoted to the population with low level education to increase their knowledge and to reduce the psychosocial barriers during risk communication.

The effects of exposure factors on public risk perceptions were consistent for both extreme heat and extreme cold scenarios. When controlling for other factors, the results suggested that respondents in Beijing and Harbin who have been exposed to unusual temperatures were more likely to perceive a higher severity of extreme heat/cold and related health risks. A 1 °C increase in temperature during survey period (temperature ranged from 25.8–37.3 °C in Beijing) was associated with an increased probability that the respondents would perceive more serious extreme heat in Beijing. While On the other hand, a 1 °C increase in temperature would lead to a decreased probability of perceiving serious extreme cold and cold-related health risks in Harbin (temperature ranged from −27.89 to −2.61 °C during survey period) (see Fig. 1). This finding could provide a possible future perspective, whereby if local extreme temperatures continue to rise due to climate change, gradual changes in local climate might stimulate public risk perception on temperature extremes. Therefore, more individuals are likely to perceive extreme temperature differently based on their local temperature change. This is a novel way to explore and quantify the relationship between temperature and public risk perception, which showed a similar relationship between changes in temperature and human health in epidemiology (Hajat and Kosatky, 2010). This suggests that the public risk perception of extreme temperature under climate change has already been shaped and will increase according to the extent of local temperature changes. This is a highlight of future adaptive and mitigation policy-making for climate change driven disasters.

In addition, the exposure to extreme temperature anomalies within one week before the survey could also significantly affect an individual's perceptions of major extremes in heat temperature (see Fig. 2). These results are similar to previous conclusions whereby the latest exposure to temperature anomalies could influence an individual's perceptions of extreme temperatures (Howe et al., 2013). In addition, our findings might partially explain the significant seasonal bias on the perception of local climate changes reported by Howe et al. (2013). Specifically, recent short-term extreme temperature perturbations within one week might be easily noticed and remembered by individuals, so that it is more possible to elicit an individual's higher concern and extreme heat (cold) perception in warm (cold) seasons. This result also helps identify an appropriate time period to communicate with the public about extreme heat temperature and its possible health impacts. Within one week of an extreme heat event, the public's perception should be appreciated and addressed even if they seem unfounded. Risk communication messages should include specific information about what the public can do to make them safer (The Regional Office for Europe of the World Health Organization, 2008; Wolf et al., 2010). When temperature extremes become more frequent in the future (Stocker et al., 2014), individuals might increasingly strengthen their perceptions based on their local short-term exposure. Thus, effective communication would be more important to promote adaptation.

The results also reveal that self-reported extreme temperature experience had a direct effect on extreme temperature severity perception. We defined an individual experience of health damage due to extreme heat/cold and an individual's weak health situation as vulnerability factors, which could make individuals suffer from extreme changes in temperature more easily. Compared to respondents who self-reported never experiencing extreme heat or cold since 2010, respondents who experienced and suffered from these natural disasters exhibited a significantly higher probability of perceiving severely extreme temperatures (Table 4). These findings suggest that the self-experience of extreme changes in temperature is a critical motivator that enhances individual perceptions as well as the causes of risk perception (Wachinger et al., 2013). This is consistent with previous studies by Spence et al. (2011). A negative self-experience, such as adverse health effects during extreme heat/cold, might be a much stronger motivator that links climatic change and individuals themselves compared with other variables. Therefore, individuals could recognize the severity of extreme temperature and have a higher perception of the related health risks based on their own actual experiences. Similarly, residents with chronic diseases also presented higher level of extreme cold and heat perception. This suggests that these vulnerable groups are being altered by temperature extremes (Adger et al., 2013) and should be the primary target of adaptive strategies.

Respondents who owned ACs and effective heating systems presented opposite effects on extreme temperature severity perception. We initially found, compared to ACs or heating systems owners, that residents without ACs showed a declining possibility of perceiving serious extreme heat, while those without heating systems presented an increasing perception level. AC is an important adaptation strategy against extreme heat in the summer (Lane et al., 2013; Wolf et al., 2010), whereas heating systems are indispensable adaptations widely adopted in North China throughout the winter(Chen et al., 2013). Both systems were critical adaptive factors in the current study. The difference may be due to the fact that AC is not the only way for residents to resist extreme heat, while effective heating system was essential for residents adapting to extreme cold. It is difficult for residents without heating system to resist the cold weather, so residents living in poorly heated houses would be more vulnerable and survey respondents without access to heating systems perceived more serious extreme cold temperature. People living without AC may tolerate to the current high temperature and may not think the extreme heat temperature is serious enough for them to buy costly cooling equipment. Besides, they could also prefer alternatives to ACs, such as fans, ventilation, or trees shading to reduce heat absorption and exposure (Akompab et al., 2013; Lane et al., 2013). This leads to an interesting implication for extreme temperature adaptation: for extreme cold, increasing the cover rate of local heating system would be effective; while for extreme heat, more heat-health risk communication were needed in motivating people to engage in adoption of possible ways (*e.g.*, using AC, wearing less clothing, selecting healthy ways of drinking/eating, leaving home for cool places, *etc.*). Risk communication should emphasize that extreme heat can be serious, hot indoor environments are dangerous during extreme heat, and that positive response to heat is a life-saving intervention for people who are vulnerable to heat illness (Lane et al., 2013).

One limitation of the present study should be addressed. Even though the 3-step sampling method was adopted, there were still some sampling bias (more female and higher educational level) in Harbin, making the sample not fully representative of the city. Consequently, this bias may influence the risk perception level since previous studies have demonstrated female and higher educational level could significantly influence perception ratings (Bronfman and Cifuentes, 2003). However, the sample structure seems acceptable in view of the fact that residents were investigated at home during working hours, during which females and high educational residents are more likely to stay at home. Larger samples from more cities located in different climatic areas should be included in further studies.

5. Conclusions

Our findings are important for promoting and regulating public health in relation to local extreme temperatures. In particular, since the public could perceive seriousness and health risks in outbreaks of extreme heat and cold temperature, this provides a good opportunity to implement public health interventions by improving risk communication and directing educational efforts in responding to local extreme temperature in China. Furthermore, predicting public responses to extreme heat and cold events of vulnerable groups may aid health risk intervention strategies to recognize priorities and targets effectively. We suggest that improvement of adaptation should be accompanied with risk communication, which could maintain public awareness and response to the potential risks posed by extreme temperatures. Specifically, the public should be educated on the concept of local temperature extremes driven by climate change as well as be offered effective guidelines for health protection, adaptation and mitigation.

Author contribution statement

Jie Ban and Tiantian Li designed the study. Jie Ban, Chen Chen, and Lei Huang designed the questionnaire, Jie Ban and Tiantian Li conducted the survey, Jie Ban cleared the survey data. Jie Ban and Tiantian Li conducted the statistical analysis. Yuming Guo and Mike Z. He co-wrote the manuscript. All authors contributed to the interpretation of the results, and approved the decision to submit the manuscript for publication.

Conflict of interest statement

We declare that we have no conflict of interest.

Ethics statement

This study was reviewed and approved by the Ethics Committee of China CDC and Harbin CDC. Written informed consent was obtained from all participants.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.scitotenv.2016.11.064.

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