The Influence of Summertime Heat Waves on Emotional Health

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Research

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Abstract

Background

With increases in global urbanization and global warming, there are corresponding increases in urban heat island effects. Heatwave disasters are occurring more frequently, bringing direct and indirect mental health hazards to urban residents. Understanding the mechanism of the impact of high ambient temperatures on emotional health is a scientific problem that needs clarification.

Methods

Data collected through an emotions questionnaire and temperature data measured on heatwave days were analyzed using GIS, SPSS and MATLAB software to study the influence of heatwaves on the negative emotions of middle-aged and elderly people (over 40 years old).

Results

The results indicate that the degree of influence of high temperatures on various negative emotions differs significantly, as some emotional responses tend to fluctuate while others steadily worsen. The progression of emotional responses is distressed > irritable > nervous > hostile. With increasing temperatures, phase-based changes in emotional states occur, with different emotional states corresponding to different temperature thresholds; the temperature thresholds for distress/nervousness/hostility were shown to be 38°C/43°C, 40°C/44°C, 43°C, respectively.

Conclusion

Ambient temperatures exceeding 35°C have a significant negative impact on the emotional health of middle-aged and elderly people. Irritability and nervousness monotonically increase, while distress and hostility tend to fluctuate. This study contributes to the prevention and management of the harmful effects of heatwaves on emotions, providing basic information applicable to designing layouts for urban green spaces to reduce the effects of urban heat islands.

Background

In recent years, with the acceleration of global urbanization, the intensity of and the areas affected by the heat island effect have been rapidly expanding, resulting in increases in the intensity, frequency, and duration of summer high ambient heat waves [1]. These heat waves expose the human body to a continuously elevated ambient temperature [2], which seriously endangers the physical and mental health of urban residents [3], with especially the elderly being significantly affected [4, 5].

The association between high ambient heatwaves and physical health has been widely studied [6, 7], but relatively few studies have been done related to mental health [8, 9]. Most studies have focused on suicide and mental illnesses and pointed out that heatwaves are significantly correlated with increased

suicide, hospital admission of psychiatric patients, and risk of acute illnesses [10, 11]. These studies have shown that heatwaves can affect the mental health of humans, but the focus has been on the effect of psychiatric illnesses [12,13], with less attention being paid to the emotional health of the general population.

Extremely high ambient temperatures pose significant risks to emotional health [11] and thermo-sensitive physiological mechanisms contribute to sleep disturbance, exhaustion, and heat stress [14, 15] which may, in turn, lead to anxiety, fatigue, emotional discomfort, and changes in mental states [16], reduced emotional health and increased aggression [17]. Related studies have shown that when the ambient temperature exceeds 21°C, positive emotions (e.g. joy, happiness) decrease and negative emotions (e.g. stress, anger) increase; above 32°C, negative emotions rise significantly [18]; and, above 35°C, affective disorders increase significantly [19]. However, these studies mainly looked at the overall effect of low and mid-range temperatures on mood, while studies on high-range temperatures are obviously lacking. Also, these studies did not dive deeper into the specific elements of negative emotions. Therefore, this research was designed to build on the foundational knowledge from previous studies and to clarify the impacts of heatwaves with temperatures above 35°C by analyzing the effects on negative emotions such as irritability, distress, nervousness, and hostility in middle-aged and elderly people.

At present, research on the mental health hazards of heat islands is very limited [20], and existing research results are mostly based on social and cultural backgrounds and the spatial composition of urban areas in Western countries. In this study, Nanjing, a typical mega-city affected by heatwaves, was used as the venue of research. Data from a survey of emotions on days with heatwaves and from measured temperatures were processed and analyzed using software such as GIS, SPSS, and MATLAB to determine the effects of heatwaves on elements of negative emotions in middle-aged and elderly populations (40 years of age and older). The study aimed to provide results that can clarify ways to help reduce the hazards of heat islands on emotional health and improve the planning and construction of healthy cities.

Methods

Questionnaire design theories and methods

Emotions are compositions produced by the physiological and psychological reactions to positive or negative information in an ongoing environment [21]. The two-dimensional emotion model theory divides emotions into two types: positive emotions (active) and negative emotions (passive) [22]. Studies have shown that emotions affect health and behaviors and reducing negative emotions has become a common strategy for managing health and behavioral problems. Hence, it is necessary to evaluate the intensity and forms of negative emotions; adjectives are often used as terminologies to describe emotions and measure their intensity. Zevon and Tellegen measured emotions by selecting 60 adjectives to describe emotions [23]. Watson et al. chose 20 of these to represent positive or negative emotions and constructed a positive-negative emotion scale for measuring the intensity of both positive and negative

emotions. Some of the adjectives chosen include “distressed,” “upset,” “guilty,” “scared,” “hostile,” “irritable,” “ashamed,” “nervous,” “jittery,” and “afraid” [24]. Huang et al. conducted research on the applicability of this emotion scale to the Chinese population, showing that this scale is suitable for use in said population [25]. The scale is widely used to assess the mental health of a community [26,27].

According to our aim and target group, this study constructed a scale to measure the influence of high temperatures in summer on urban residents’ emotions based on the theory and practice of emotional health measurement. This scale fully considers the high ambient temperatures stated in the questionnaire and the correlation between negative emotional elements and the environment. Therefore, this questionnaire uses an abbreviated list of 4 elements—distressed, irritable, nervous and hostile—for measurement. The reliability and validity examination of this questionnaire showed a Cronbach’s α coefficient value greater than 0.71, and a KMO value of 0.715, indicating that the questionnaire has good validity, possesses consistency and reliability, and can be used in this research.

Data source

Nanjing City (31°14"-32°37"N, 118°22"-119°14"E) is a very densely populated megacity in China with a population of 8,436,200. It was the 24th largest Asian City in 2018 and was considered a second-tier city in the world in 2018. Nanjing has a subtropical humid climate with four distinct seasons and abundant rainfall. The annual average temperature is 15.4°C and the average daily maximum temperature in the summer of 2019 was 31.1°C.

With the rapid growth of the population and economy, Nanjing has urbanized rapidly, the urban heat island effect has continuously increased, and heatwave disasters have occurred frequently, with negative impacts on the physical and mental health of urban residents. Hence, it is meaningful to study the effects of heatwaves on the emotional health of residents in Nanjing.

Questionnaire

The sample data were derived from a random questionnaire survey of “The effects of heatwaves on the emotional health of urban residents” from 28 July to 27 August 2019 in Nanjing, China. The survey targeted middle-aged and elderly people over 40 years of age who were traveling outdoors on days with heatwaves. The locations were distributed among major residential areas, squares, and parks in Nanjing in areas both north and south of the Yangtze River. The samples cover the high, medium, and low-temperature areas of the urban area (Figure 1). The specific contents of the questionnaire included “Do you feel distressed now?” “Do you feel hostile now?” “Do you feel irritable now?” and “Do you feel nervous now?”. For each question, the respondent could choose to answer “1, very slightly or not at all,” “2, a little”, “3, moderately,” “4, quite a bit,” or “5, extremely,” or they could refuse to answer, all according to their mood at the time.

Temperature measurement

The temperature data were obtained from a small WS-30 handheld weather station 1.5 m above the ground (Figure 2). The accuracy of the device is $\pm 0.3^{\circ}\text{C}$ and it automatically records the temperature once per minute. It has the advantages of fast response and high precision and is suitable for use in urban outdoor environments. The temperature recording was based on the thermistor principle, where electrical resistance changed with the temperature. The weather stations are consistent with the locations on the questionnaire and are mainly located in the central open space of major residential areas, squares and parks in areas both north and south of the Yangtze River.

Data processing

A total of 992 questionnaires were distributed in this survey; 417 of them were collected, and invalid questionnaires—such as those that were blank, incomplete, or indicated respondents were aged below 40 years—were excluded. A total of 386 valid questionnaires were obtained after screening. According to the recorded time on the questionnaires, the questionnaire data were matched with the temperature data at the same time in the corresponding place, and the temperature data of the survey were divided into equal intervals of 1°C . The study focused on the impact of heatwaves on urban residents. The definition of heatwaves in China is that the maximum daily temperature reaches or exceeds 35°C for more than three consecutive days, and insufficient temperature sample sizes above 50°C may affect the accuracy of data smoothing, so this study intentionally set the analyzable temperature range at $35\text{--}46^{\circ}\text{C}$.

Using crosstab analysis in SPSS, the percentages of the degrees of influence of the four elements in each temperature range, namely irritability, distress, nervousness, and hostility, were obtained. Then, the percentages of the degrees of influence of the four elements were weighted to obtain the comprehensive influence degree index of the elements in each interval. In addition, the data were smoothed, and the impact indicators were normalized according to the maximum value.

Using MATLAB's curve fitting toolbox (CFTool), a variety of curve regression analyses were performed. The relationship model between temperature and emotional elements was constructed, and the respective equations with high regression results of high temperature with irritability, distress, nervousness, hostility were derived.

Result Analysis

Sample analysis

The sample temperature data box plot was drawn using SPSS software to analyze the distribution of the data (Figure 3). The results show that the sample data covered a range between $30\text{--}52^{\circ}\text{C}$ and have a good spatial distribution. The interquartile range is 9°C , which accounts for 40.91% of the range, indicating that the temperature samples were not concentrated in certain intervals, but are distributed in various intervals, which ensures a sufficient number of samples in each interval. At the same time, the median was 42°C , indicating that the sample can better cover the heat waves above 35°C relatively well.

Basic descriptive analysis shows that the samples can be used to study the effects of high-temperature heat waves on residents' emotional health.

Correlation analysis between high temperature and emotional elements.

The correlation coefficient analysis between high temperature and emotional elements indicates that the correlation coefficients for high temperature and irritability, high temperature and hostility are positive, and the reliability test of 0.00 (Table 1) indicates that these two have significant positive correlation. The correlation coefficient of distress did not pass the reliability level test, but the segmentation correlation analysis of the original data according to the temperature found that the temperature of 35-38°C was positively correlated with distress, with a correlation coefficient of 0.309, and the test had a reliability level of 0.006; a negative correlation was found at 38-43°C with a correlation coefficient of -0.256, and passed the reliability level of 0.004 (Table 2). This shows that high temperature and distress are closely correlated.

The correlation analysis between high temperatures and emotional elements was studied through Grey correlation analysis. The results showed that the absolute correlation degree indicators of high temperature and emotional elements were irritability > hostility > nervousness > distress; the composite correlation degree index followed the sequence of nervousness > irritability > distress > hostility (Table 3). The absolute correlation index only reflects the similarity between the temperature and emotional elements curve and is similar to the correlation analysis calculation method. Therefore, the calculation results are similar, indicating that irritability and hostility have higher correlation, while nervousness and distress have lower correlation. However, the composite correlation coefficient reflected the complex relationship between the similarity of the curves and the closeness of the rate of change, so it is inconsistent with the correlation analysis and the absolute correlation degree, which indicates that nervousness and irritability also have a very high correlation. This close relationship is hidden in the changes of different temperature stages.

Correlation analysis showed that high temperature was correlated with distress, irritability, and hostility, but not with nervousness. This is because the correlation analysis is for linear correlation factors, while the Grey correlation analysis does not have this precondition. The Grey correlation analysis is applicable to linear and non-linear curves. Under low data requirements, the correlation between high temperature and the four elements of emotional health could be seen. Therefore, the correlation coefficient and the absolute correlation coefficient indicate that high temperature has a clear relationship with irritability, hostility, and distress. The composite correlation index indicates that high temperature has a stronger correlation with nervousness and irritability than with distress and hostility. Therefore, this paper decides to explore the relationship of high temperature with irritability, distress, hostility, and nervousness separately.

Relationship between high temperature and distress

There is a clear correlation between high temperature and distress. Using MATLAB's regression analysis, it is found that a quadratic curve can be well-fitted between the two, and the regression equation is:

[Due to technical limitations, equation 1 only available in the manuscript file below.]

where R^2 is 0.98, and RMSE is 0.015. The regression equation shows that (Figure 4) as the temperature rises, the effect of high temperature on distress changes in stages: at 35–38°C, the degree of influence rises rapidly; at 38–43°C, the degree of influence decreases gradually; at 43–46°C, this again increases gradually. The main reason for this is that at 35–38°C, the human body's ability to regulate in high temperatures can initiate an emergency warning mechanism. At this time, the high temperature is not perceived as a threat and the degree of arousal is not high, so it is a phase with increasing distress [28]. At 38–43°C, the body temperature regulation mechanism enters the second-level early warning stage, the human body begins to protect itself and enters the resistance stage, the superficial veins dilate, the blood circulation is competent and perspiration is increased. The body's energy is focused on coping with the external stimulation, thus bringing down the level of distress psychologically [29,30]. At 43–46°C, the temperature critically exceeds the effective adjustment range of the physiological warning system, and the individual consumes a large amount of energy in response to high temperature, the body fails to return to equilibrium and the individual once again perceives this high temperature as a threat and enters the exhaustion stage, thus presenting with the rising phase of distress [31].

Relationship between high temperature and irritability

There is a clear correlation between high temperature and irritability. Analysis shows that a cubic curve can be well-fitted between the two, and the regression equation is:

[Due to technical limitations, equation 2 only available in the manuscript file below.]

where R^2 is 0.99, and RMSE is 0.003. The regression equation shows that (Figure 5) at 35–45°C, the effect of high temperature on irritability continues to rise with increasing temperature. The main reason is that as the temperature rises, the risk of high temperature to the body increases, and the intensity of arousal rises continuously. The investment in response to ambient high temperature gradually increases [30]. At this time, the human body will be in an "easily irritated state". If one does not get one's way, one would become angry. Some people will lose their emotional control.

Relationship between high temperature and hostility

There is a clear correlation between high temperature and hostility. Analysis shows that a quadratic curve can be well-fitted between the two, the regression equation being:

[Due to technical limitations, equation 3 only available in the manuscript file below.]

where R^2 is 0.99, and RMSE is 0.001. The regression equation shows that (Figure 6) at 35–43°C, as the temperature increases, its effect on hostility rises rapidly—at 43–45°C—its effect on hostility slowly

decreasing. The main reason is that at 35–43°C, as the temperature rises, the individual will concentrate more and more energy on the regulation against ambient temperature, so the hostility to the external environment's interfering stimulation is gradually enhanced; when the temperature reaches 43°C, which exceeds the effective adjustment range of the physiological warning mechanism, the body can no longer return to equilibrium. At this time, an individual only wants to escape from this hot environment [32], which gradually decreases hostility.

Relationship between high temperature and nervousness

There is a clear correlation between high temperature and nervousness. Analysis shows that a cubic curve can be well-fitted between the two, with the regression equation being:

[Due to technical limitations, equation 4 only available in the manuscript file below.]

where R^2 is 0.95, and RMSE is 0.005. The regression equation shows that (Figure 7), as the temperature increases, its effect on nervousness changes stage by stage. At 35–40°C, the degree of influence increases rapidly; at 40–44°C, the degree of influence is in a stationary stage; at 44–46°C, the degree of influence slowly rises. This is mainly because as the temperature increases, the level of emotional arousal rises, and its superposition with the unpleasant feeling brought by high temperature leads to emotional nervousness [28]. With the initiation of the body's early warning mechanism for high temperature, individuals will focus on coping with environmental stimuli, and this nervousness enters a table stage.

Difference in the effects of high temperature on negative emotional elements

The effects of high temperature on different negative emotional elements were compared and it was found that the elements were affected by high temperature differently: distressed > irritable > nervous > hostile (Figure 8). The influence of high temperature is fluctuant on distress and hostility, is monotonically increasing on nervousness and irritability. The reason is that the impact of high ambient temperature on the human body is multi-layered and increases layer by layer. When the human body enters an environment with high temperature, the psychological response is often more sensitive than other responses, and in the scenario of slow adaptation, the human body responds to the high temperature emotionally through distressed and anxiety. When extreme or prolonged high temperatures cause negative physical and mental responses beyond the physiological and psychological tolerance of the human body, an individual will show impulsive irritability.

Combined effects of high temperature on negative emotions

The combined effect of high temperature on negative emotions is the comprehensive process of distress, irritability, nervousness, and hostility in individuals. Therefore, this paper will superimpose these four

elements to analyze the composite effects of high temperature on emotional health. The results show that the regression equation for the combined effect of high temperature on negative emotions is:

[Due to technical limitations, equation 5 only available in the manuscript file below.]

where R^2 is 0.97, and RMSE is 0.006. The regression equation shows (Figure 9) that

the effect of high temperature on emotional health appears to change in stages: Overall, the higher the ambient temperature, the worse the negative emotions. At 35-39 °C, with the increase in ambient temperature, degree of influence increases rapidly; at 39-43°C, the relationship between temperature and mood entered a stage of reverse changes, and the degree of influence decreases slightly with temperature. After 43°C, the negative emotion again rises but the rate is lower than at the 35-39°C stage. This indicates that individuals have different emotional characteristics in different temperature intervals in response to environmental stimuli.

Discussion

In this study, the direct questionnaire survey method was used to analyze the impact of heatwaves on emotional health, which facilitated real-time acquisition of real emotional state and intensity in high-temperature environments, avoiding the time lag error of interviews. The positive and negative emotion scale contains 20 factors, and the subjects needed to stay and to be interviewed for a long time. Because humans can stay in a high-temperature environment for a short period of time, too many questions will lead to high rejection rate of the questionnaire. At the same time, in the high-temperature environment, the subjects' emotions are affected by high temperatures. Long-term interviews may lead to an increase in negative emotions, affecting the accuracy of the research results. The questionnaire was therefore reduced to only four elements. The elements were derived from the negative emotions of the positive and negative emotion scale. Four factors closely related to high temperature and environmental impact were selected from the scale, including distressed, irritable, nervous and hostile, excluding scared, ashamed, nervous, afraid, etc. which are not closely related.

The questionnaires in this study were based on random sampling, so it could not be ruled out that the subjects might be affected by their previous activities or sudden events. In order to minimize the error of these effects on data analysis, this study, while ensuring the randomness of sampling, preliminarily screened the subjects, excluded people who were strenuously exercising, and expanded the sample data to 386 cases.

This study selected the middle-aged and elderly population to analyze the general characteristics of the effects of high temperature on emotional health and did not consider gender, economic conditions, education level, etc. This is because this study is a preliminary study on the middle-aged and elderly population, and only explores the most probable general patterns. The results show that the effects of high temperatures on the emotional health of people over 40 years have a general, but in the age group

over 65 years, the pattern of emotional elements affected by high temperature is more prominent, and some curves showed lags. The data showed that the influence on the population aged 65 and over was weaker than that on the 40-65 population at 39-42°C, and the threshold temperature was increased by 1°C compared with those over 40 years. In the next step, we will focus on in-depth studies in the 65+ age group, taking into account different factors such as gender, economic conditions, and education.

There are some limitations to this study. This study only investigates a typical megacity in East Asia, and whether the relevant research results can be adapted to cities in other regions needs further verification.

Conclusion

(1) When the ambient temperature exceeds 35 °C, it has a significant impact on the emotional health of middle-aged and elderly people. The influence degree of comprehensive negative emotions and emotional elements generally rise with the increase in temperature.

(2) The degrees of influence of high temperature on different negative emotional elements are significantly different, and the degrees of influence are in the following sequence: distressed > irritable > nervous > hostile.

(3) With the increase of temperature, the influence of high temperature on emotional elements shows phased changes, and different emotional elements have different threshold temperatures. The threshold temperatures of distressed are 38°C and 43°C, the degree of influence at 35–38°C and 43-46°C is enhanced, and the degree of influence at 38-43°C is weakened; the influence on irritability is continuously increasing; the threshold temperatures of nervousness are 40°C and 44°C, the influence degree at 35–40 °C and 44-45 °C is enhanced, and the influence degree at 40–44°C is in a stationary stage; the threshold temperature of hostility is 43°C, the degree of influence at 35–43°C is enhanced, and the degree of influence at 43–46 °C is weakened.

This paper studies the relationship between heat waves and emotional health, which is beneficial to reducing the harmful effects of heatwaves on emotions, and also provides the basic research for urban green space layout. In the next step, we will combine the green space layout of the survey site to explore the planning improvement measures for the psychological healing function of green space, in order to provide reference for constructing healthy urban planning and construction.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and materials: The dataset is available from the corresponding author upon request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: HHC performed the data analyses and developed the study protocol. DX contributed significantly to analysis and refined the manuscript. YHL revised the manuscript. CTN helped perform the analysis with constructive discussions. LJJ played an important role in interpreting the results. All authors commented on the manuscript at various stages. All authors read and approved the final version of the paper.

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Tables

Table 1 Correlation coefficient between high temperature and emotional elements

	Distress	Hostility	Irritability	Nervousness
Pearson’ correlation	.048	.179 **	.183 **	.063
Significance (two-tailed)	.352	.000	.000	.218

Table 2 Segmentation correlation analysis of high temperature on distress

35–38°C	Pearson’s correlation	.309 **
	Significance (two-tailed)	0.006
38–43°C	Pearson’s correlation	-.256 **
	Significance (two-tailed)	0.004

Table 3 Absolute correlation degree and composite correlation degree between temperature and emotional elements

	Distress	Irritability	Nervousness	Hostility
Absolute	0.5398	0.6204	0.547	0.5862
Composite	0.6632	0.6913	0.7193	0.604