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. Heat wave disasters are occurring more frequently, posing direct and indirect mental health hazards to urban residents. The impact of high ambient temperatures on emotional health is a scientific problem that needs clarification. Methods: Data collected through 386 valid emotions questionnaire and temperature data measured on heat wave days were analyzed using GIS, SPSS and MATLAB software to study the influence of heat waves on the negative emotions of middle-aged and older adults (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, and hostility were shown to be 38°C/43°C, 40°C/44°C, 43°C, respectively. Conclusions: Ambient temperatures exceeding 35°C have a significant negative impact on the emotional health of middle-aged and older adults. 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 heat waves on emotions, providing basic information applicable to the design of 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 and range of the urban heat island effect (UHI) have been rapidly expanding, resulting in increases in the intensity, frequency, and duration of summertime 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 temperatures and physical health has been widely studied [6, 7], but relatively few studies related to mental health [8, 9] have been conducted, most of which focused on suicide and mental illnesses. In these studies, heat waves were shown to be significantly correlated with increased suicide, hospital admission of psychiatric patients, and risk of acute illnesses [10,11]. While the research has shown that heat waves can affect the mental health of humans, the focus has been on the effect on psychiatric illnesses [12,13], with less attention paid to the emotional health of the general population.

Extremely high ambient temperatures pose significant risks to emotional health [11]. 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 state [16], along with 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. Further, previous studies did not explore the constituent elements of negative emotions. Therefore, the current study was designed to build on the foundational knowledge from previous studies, and to clarify the impact of heat waves with temperatures above 35°C on negative emotions, such as irritability, distress, nervousness, and hostility, in middle-aged and older adults.

Methods

At present, research on the mental health hazards of UHIs is very limited [20], and existing research results are mostly located in the social and cultural backgrounds and spatial composition of urban areas in Western countries. The current study was located in Nanjing, a typical megacity affected by heat waves. Data collection was done on days with heat waves, using a survey of emotions and temperature measurements. Collected data were processed and analyzed using a geographic information system (GIS) and the software applications SPSS and MATLAB, to determine the effect of heat waves on elements of negative emotions in middle-aged and elderly populations (40 years and older). The study aimed to clarify ways of reducing the hazards of UHI to emotional health, and improving the planning and construction of healthy cities.

Questionnaire Design

Emotions are produced by an individual’s physiological and psychological reactions to positive or negative information in an ongoing environment [21]. The two-dimensional model of emotions distinguishes between positive (active) and negative (passive) emotions [22]. Studies have shown that emotions affect health and behavior, 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 to describe emotions and measure their intensity. Zevon and Tellegen measured emotions by selecting 60 adjectives to describe emotions [23], while Watson et al. chose 20 of these adjectives, including “distressed,” “upset,” “guilty,” “scared,” “hostile,” “irritable,” “ashamed,” “nervous,” “jittery,” and “afraid,” to represent positive or negative emotions, and constructed a positive-negative emotion scale for measuring the intensity of both positive and negative emotions [24]. Huang et al. showed that this scale is applicable to the Chinese population [25], and it has been widely used to assess the mental health of communities in China [26,27].

Informed by the study aims and target population, we developed a scale to measure the influence of high summertime temperatures on urban residents’ emotions, based on the theory and practice of emotional health measurement. This scale fully considers the high ambient temperatures above 35°C stated in the questionnaire and the correlation between negative emotional elements and the environment. The questionnaire used an abbreviated list of four adjectives, or negative emotional elements, namely distressed, irritable, nervous and hostile, for measurement. The reliability and validity assessment showed a Cronbach's α coefficient value greater than 0.71, and a KMO value of 0.715, indicating that the questionnaire had good validity, possesses consistency and reliability, and were appropriate for this study.

Study Setting

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 the same year. 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, with a concomitant increase in the UHI. Heat wave disasters have occurred frequently, with negative impacts on the physical and mental health of urban residents. Hence, it is meaningful to study the effect of heat waves on the emotional health of residents in Nanjing.

Data source

Sampling

The sample data were derived from a random questionnaire survey from 08:00–12:00 and 14:00–17:00 from 28 July to 27 August 2019 in Nanjing, China. A face-to-face interview using a questionnaire was done asking the effects of heat waves on the emotional health of urban residents. 992 people were interviewed and only 417 accepted our questionnaires. The survey targeted middle-aged and older adults over 40 years of age who were traveling outdoors on days with heat waves. According to the preliminary investigation and traffic statistics survey data from Bureau of land and space planning, the interference of regular activities, such as sending and receiving children to and from school, commuting traffic, were excluded. These activities influenced the results of bivariate studies of temperature and mood. The locations were distributed among major residential areas, squares, and parks in Nanjing, both north and south of the Yangtze River. The sampling covered the high, medium, and low-temperature areas of the urban area (Fig. 1), and were typically representative, reducing the impact of occasional sexual factors and ensuring the stability of questionnaire interviews. The questionnaire comprised four items: "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.

The current study relied on random sampling, so it could not be ruled out that the subjects might be affected by previous activities or unexpected events. In order to minimize the error of these effects on data analysis, while ensuring the randomness of sampling, we conducted a preliminary screening of subjects to include middle-aged and older adults who had a calm state of mind while exposed to high temperatures for a certain period of time, who did not show obvious irritability, hostility, tension, or being upset, and to exclude people who were participating in strenuous exercise or stayed in the shade for a long time. Ultimately, data were collected from 386 cases.

Temperature measurement

The temperature data were obtained from a small WS-30 handheld weather station 1.5 m above the ground (Fig. 2). The accuracy of the device is ± 0.3°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 changes with the temperature. The weather stations were used consistent with the survey locations, mainly in the central open spaces of major residential areas, squares and parks, in areas both north and south of the Yangtze River.

Data Analysis

A total of 992 questionnaires were distributed; 417 were collected, and invalid questionnaires, such as those that were blank, incomplete, or completed by respondents under age 40, were excluded. A total of 386 valid questionnaires were included in the analysis.

Using the recorded time on the questionnaires, the survey data were accurately matched with the corresponding temperature data, to establish a temperature and mood survey form. First, in the preparation stage before the questionnaire, the date, place and name of the investigator were noted on each questionnaire. Second, during the questionnaire survey period, each time a questionnaire was completed, the researcher recorded the time on the questionnaire. Finally, in the initial stage of data processing, according to the time and temperature data provided by the hand-held meteorological station and the time and mood data by questionnaire survey, the mood data corresponding to the location and time were matched with the temperature data. At this stage, multiple checks were performed to ensure the correctness of the data.

The current study focused on the impact of heat waves on urban residents. In Chine, heat waves are defined as a maximum daily temperature of 35°C or more for more than three consecutive days. Insufficient temperature sample sizes above 50°C may affect the accuracy of data smoothing, so we intentionally set the analyzable temperature range at 35–46°C. The measured temperature data was divided into equal intervals of 1°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 at 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.

Results

Sample Analysis

The sample temperature data box plot was drawn using SPSS software to analyze the distribution of the data (Fig. 3). The results show that the data covered a range between 30–52°C and had good spatial distribution. The interquartile range was 9°C, which accounts for 40.91% of the range, indicating that the temperature samples were not concentrated in certain intervals, but were distributed across various intervals; this ensures a sufficient number of samples in each interval. At the same time, the median was 42°C, indicating that the sample covered heat waves above 35°C relatively well. Basic descriptive analysis showed that the sample could be used to study the effects of high-temperature heat waves on residents' emotional health.

Correlation Analysis between High Temperature and Emotional Elements

The analysis produced positive correlation coefficients between high temperature and irritability, and high temperature and hostility; the reliability test result of 0.00 (Table 1) indicates that these correlations were significant. The correlation coefficient for distress did not pass the reliability level test, but the segmentation correlation analysis of the original data according to temperature found that the temperature of 35–38°C was positively correlated with distress, with a correlation coefficient of .309**, and a reliability level of .006; a negative correlation was found at 38–43°C, with a correlation coefficient of -.256**, and reliability level of .004. This indicates that high temperature and distress are closely correlated.

Table 1. Correlation coefficients between high temperature and four emotional elements

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

** means in this table, the correlation is significant at the 0.01 level (two-tailed)

Grey correlation analysis was applied he relationships between high temperatures and the various emotional elements. 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 2). The absolute correlation index only reflects the similarity between the temperature and emotional elements curve and is similar to the correlation analysis calculation method. The calculation results are similar, indicating that irritability and hostility have higher correlations with high temperature, while nervousness and distress have lower correlations. However, the composite correlation coefficient reflected the complex relationship between the similarity of the curves and the closeness of the rate of change. Thus, 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.

Table 2. Absolute correlation degree and composite correlation degree between temperature and emotional elements

	Distress	Irritability	Nervousness	Hostility
Absolute Correlation	.540	.620	.547	.586
Composite Correlation	.663	.691	.719	.604

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, we decided 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: (see Equation 1 in the Supplemental Files) where R^2 is .98, and RMSE is 0.015. The regression equation shows that as the temperature rises, the effect of high temperature on distress changes in stages (Fig. 4): at 35–38°C, the degree of influence rises rapidly; at 38–43°C, the degree of influence decreases gradually; and at 43–46°C, the degree of influence 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 characterized by increasing distress [28]. At 38–43°C, the body temperature regulation mechanism enters the second-level 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 psychological distress [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 the 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 a 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: (see Equation 2 in the Supplemental Files)

where R^2 is .99, and RMSE is 0.003. The regression equation shows that at 35–45°C, the effect of high temperature on irritability continues to rise with increasing temperature (Fig. 5). 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 an individual does not get their way, they would become angry, and some people will lose 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: (see Equation 3 in the Supplemental Files)

its effect on hostility slowly decreases. The main reason is that at 35–43°C, as the temperature rises, the individual will concentrate increasing amounts of 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: (see Equation 4 in the Supplemental Files)

where R^2 is 0.95, and RMSE is 0.005. The regression equation shows that, as the temperature increases, its effect on nervousness changes stage by stage (Figure 7). At 35–40°C, the degree of influence increases rapidly; at 40–44°C, the degree of influence is stationary; 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.

Differences 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 fluctuates in relation to distress and hostility, while monotonically increasing with 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 distress 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 encompasses the comprehensive process of distress, irritability, nervousness, and hostility in individuals. Therefore, we have superimposed 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: (see Equation 5 in the Supplemental Files)

where R^2 is .97, and RMSE is 0.006. The regression equation shows that the effect of high temperature on emotional health appears to change in stages (Figure 9). Overall, the higher the ambient temperature, the worse the negative emotions. At 35-39 °C, with the increase in ambient temperature, degree of influence increased rapidly; at 39–43°C, the relationship between temperature and mood entered a stage of reverse change, and the degree of influence decreased slightly with temperature. After 43°C, the negative emotion again rose, but the rate was lower than at the 35–39°C stage. This indicates that individuals have different emotional characteristics at different temperature intervals in response to environmental stimuli.

Discussion

In this study, the direct questionnaire survey method was used to analyze the impact of heat waves on emotional health, which facilitated real-time acquisition of real emotional state and intensity in high-temperature environments, avoiding the time lag of interviews. The positive and negative emotion scale developed by Watson et al. [24] comprises 20 factors, requiring long interview times for respondents. Because humans can only stay in a high-temperature environment for short periods of time, too many questions will lead to a high rejection rate of the questionnaire. Furthermore, a high-temperature environment will affect subjects' emotions, and long interviews may lead to an increase in negative emotions, affecting the accuracy of the research results. The questionnaire used in the current study was therefore reduced to only four elements, derived from the negative emotions used in Watson et al.'s [24] scale. Four factors closely related to high temperature and environmental impact were selected from the scale: distressed, irritable, nervous and hostile; items that were not closely related, such as scared, ashamed, nervous, and afraid, were excluded.

We selected the middle-aged and older adults to analyze the general characteristics of the effects of high temperature on emotional health; we did not consider gender, economic conditions, education level, etc. This is because this 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 negative impact, 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 age 40. In the next step, we will focus on in-depth studies among those who are ³ 65-years-old, taking into account different factors such as gender, economic conditions, and education.

This study focused on the effect of heat waves on the emotional health of middle-aged and older adults, and the curve of temperature changes, and did not involve a control group or baseline study, using mid-range or low temperatures, for example. Previous research [18] has shown that the human body can withstand the temperature range of at 21–28°C, and the effect of temperature on negative emotions in this stage is significantly lower than at 28–35°C (Figure 10). This effect increases rapidly as the temperature rises. Above 35°C, it will cause significant harm to emotional health [11], and negative emotions will increase significantly [19]. The results of the current study show that, at 35–46°C, the effect of high temperature on negative emotions changes in stages. The influence curves of negative emotion elements (upset, irritability, hostility, and tension) vary widely, and also have different threshold temperatures. This study did not conduct a comparative analysis of the regularity of the temperature curve in the range of 21–35°C, but only focused on the high-temperature stage above 35°C, and studied the specific mechanism of the relationship between temperature and negative emotion elements.

There are some limitations to this study. First, this study only investigated a typical megacity in East Asia, and whether the results can be adapted to cities in other regions needs further verification. Second, the experiment was only performed under high temperature conditions. In the next study, data from the normal and low temperature ranges as a baseline will be included.

Conclusion

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

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

(3) With an increase in 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 continuously increases; 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 study explored the relationship between heat waves and emotional health, which is beneficial to reducing the harmful effects of heat waves 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 planning improvement measures for the psychological healing function of green space, in order to provide reference for constructing healthy urban planning and construction.

List Of Abbreviations

UHI: Urban Heat Island

Declarations

Ethics approval and consent to participate: All the participants agreed to take part in the experiment.

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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Figures

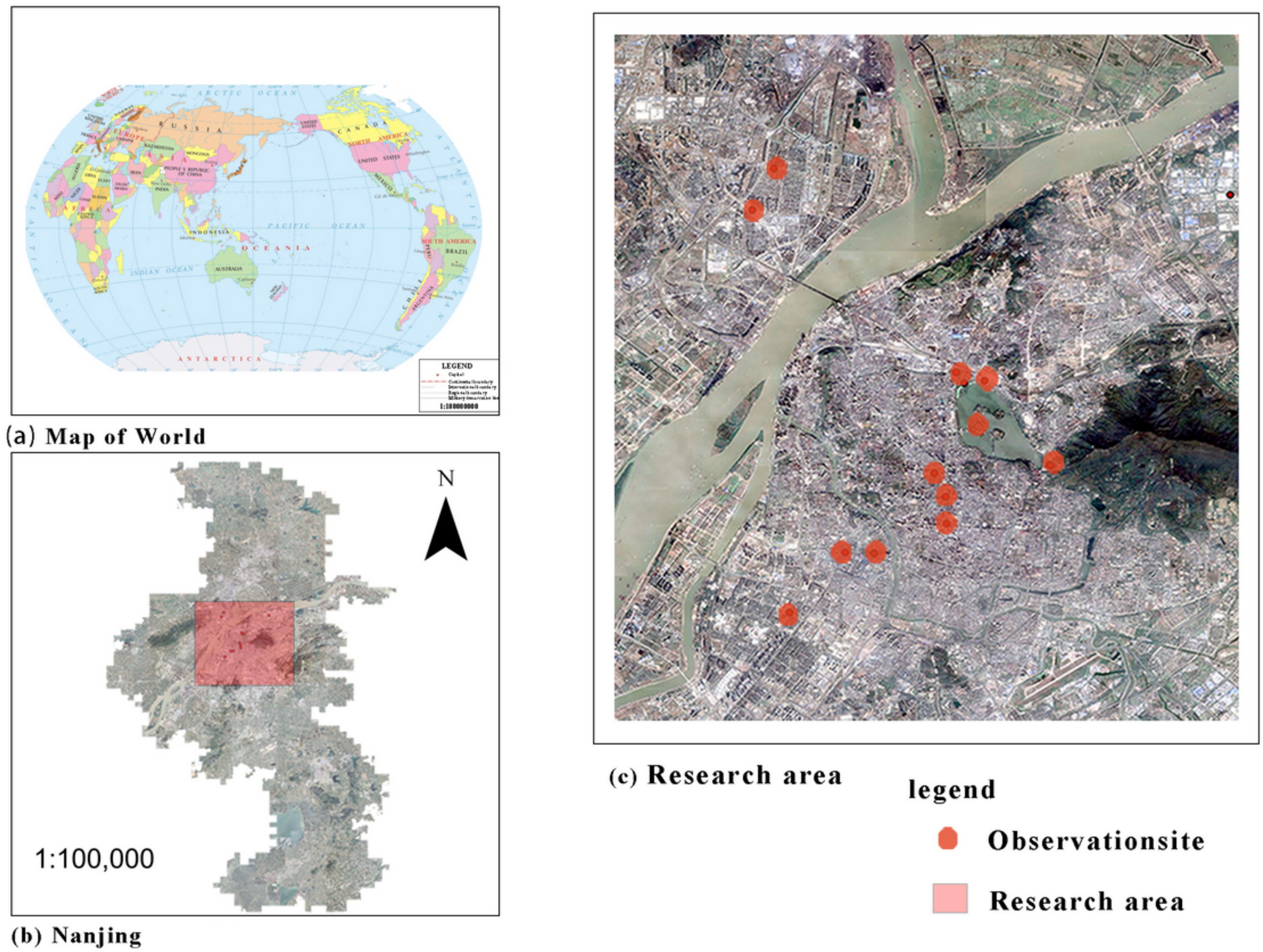

Figure 1

Research area and data collection. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Mini handheld weather station

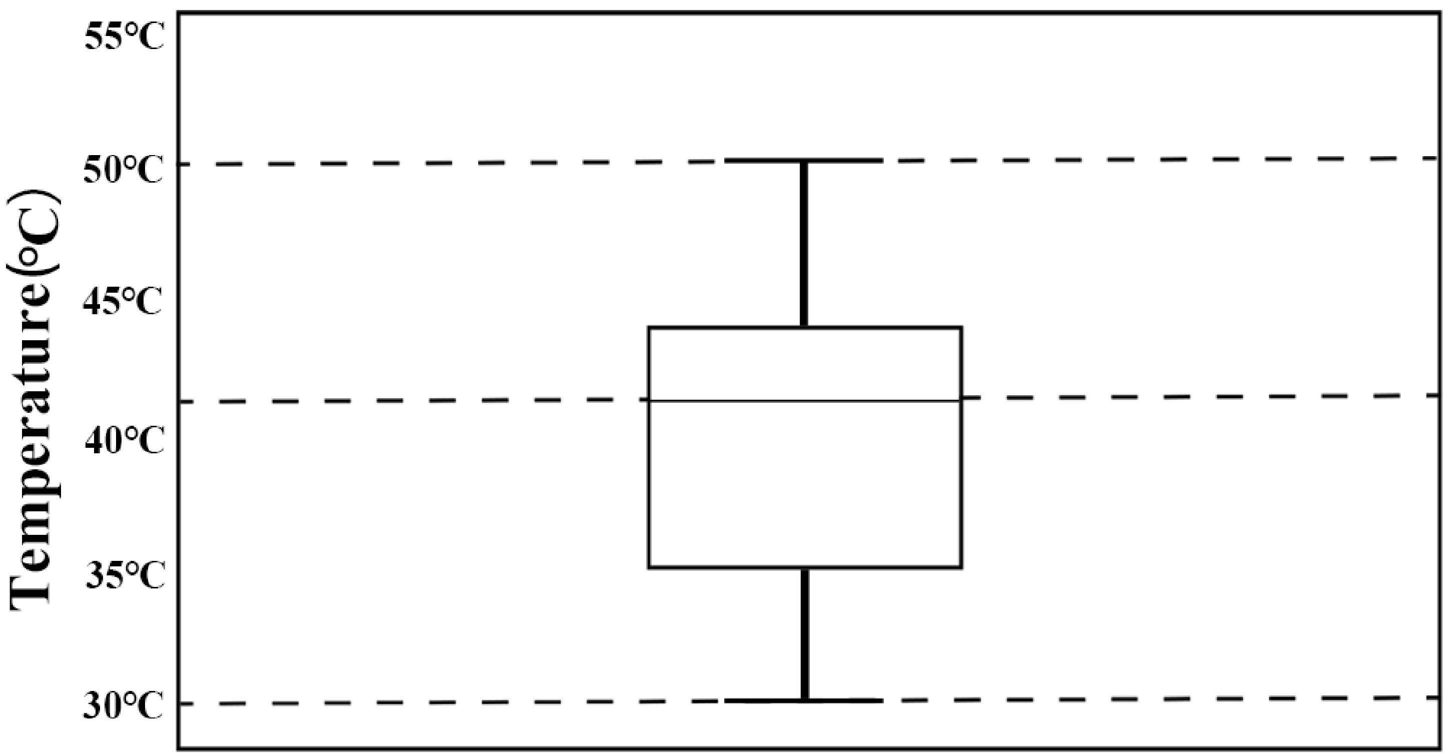

Figure 3

Sample temperature coverage intervals

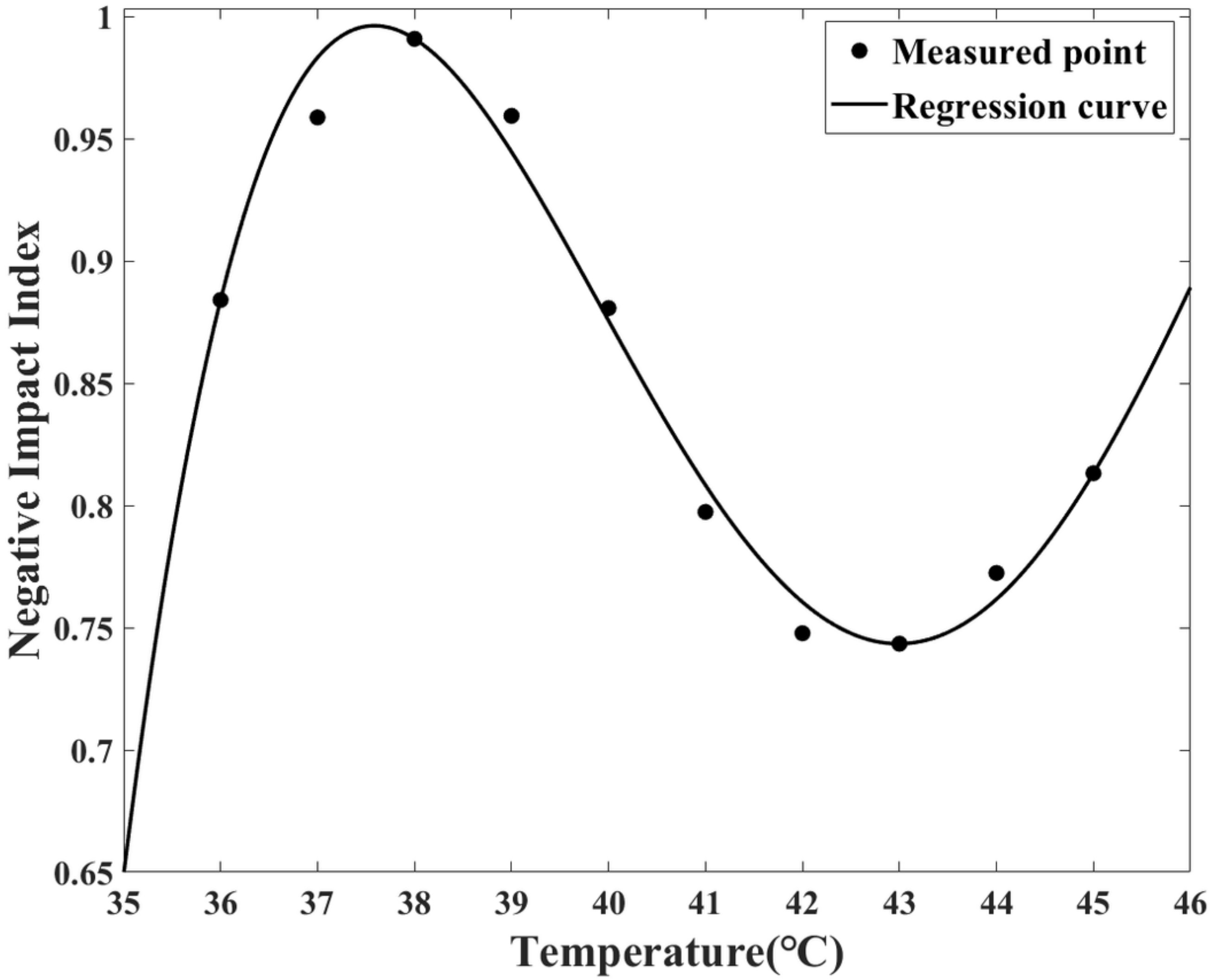

Figure 4

Effect of high temperatures on distress

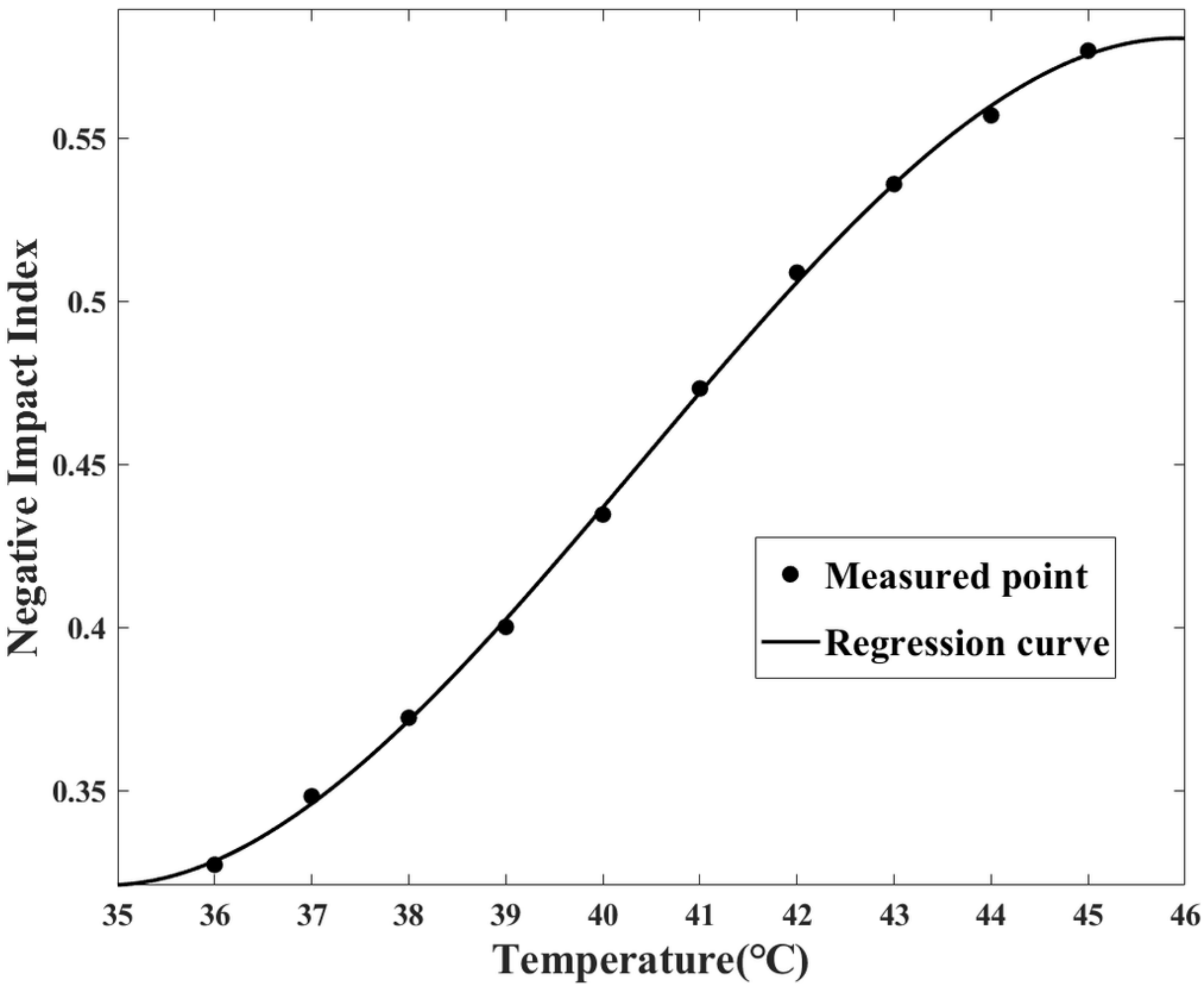

Figure 5

Effect of high temperatures on irritability

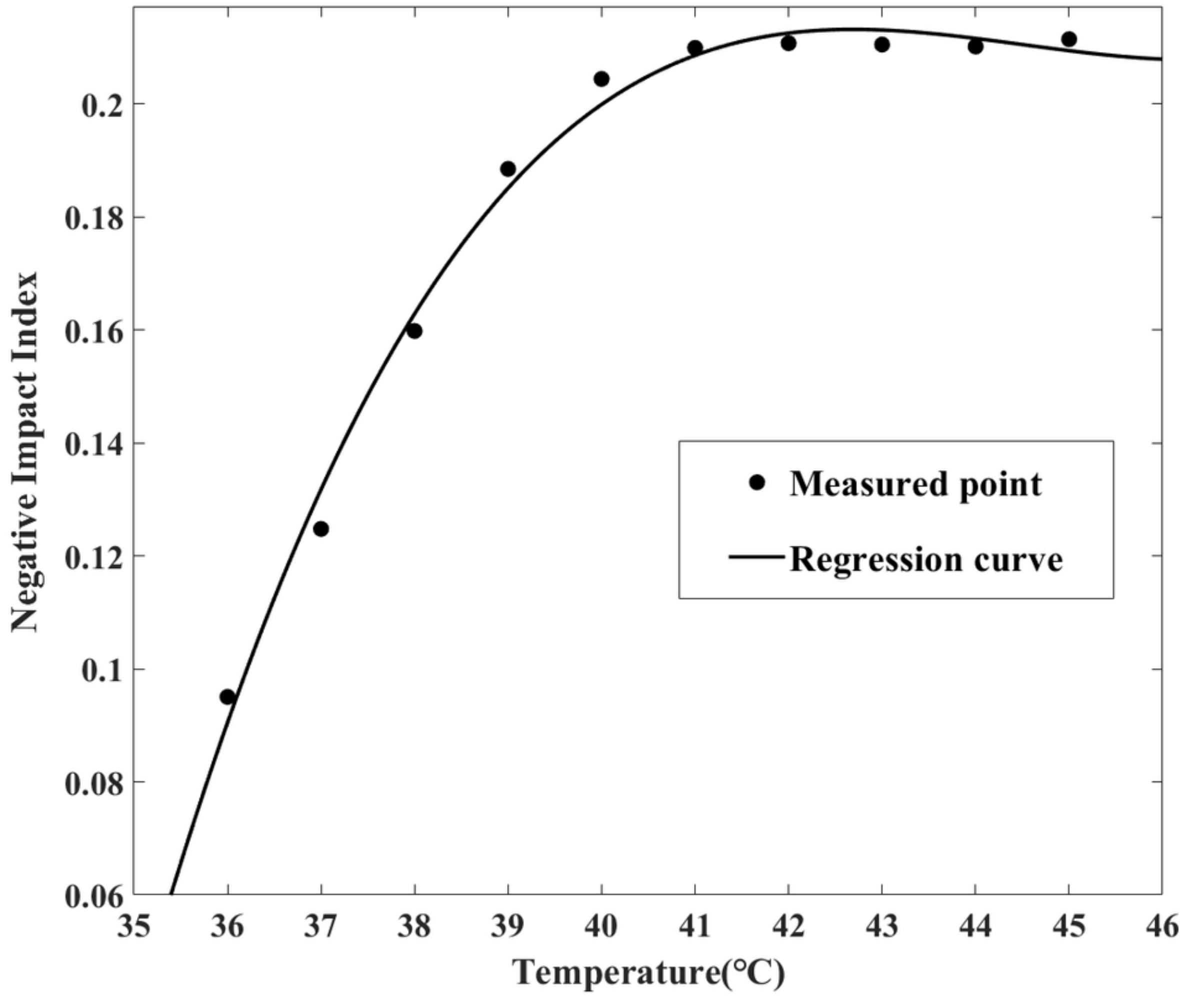

Figure 6

Effect of high temperatures on hostility

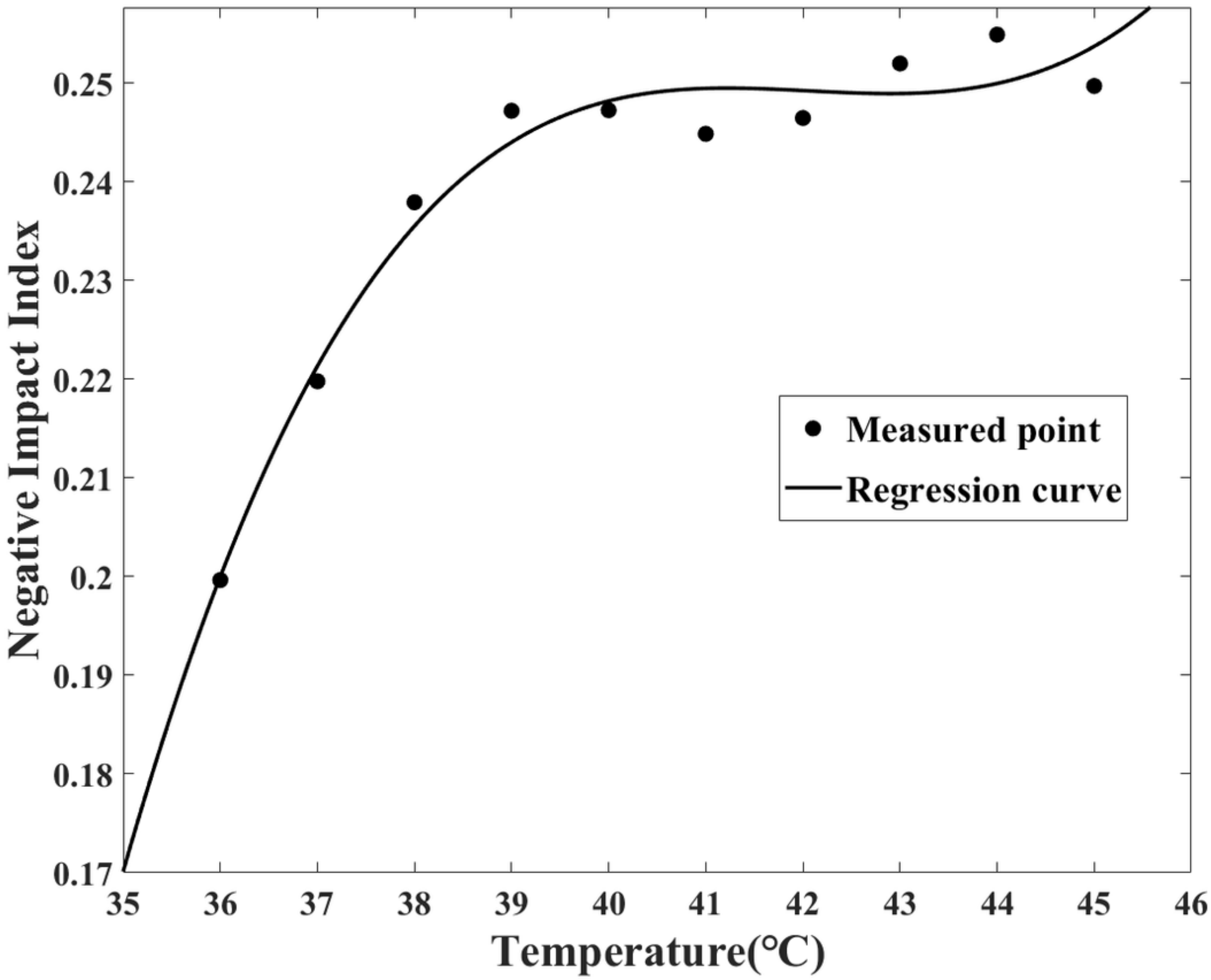

Figure 7

Effect of high temperatures on nervousness

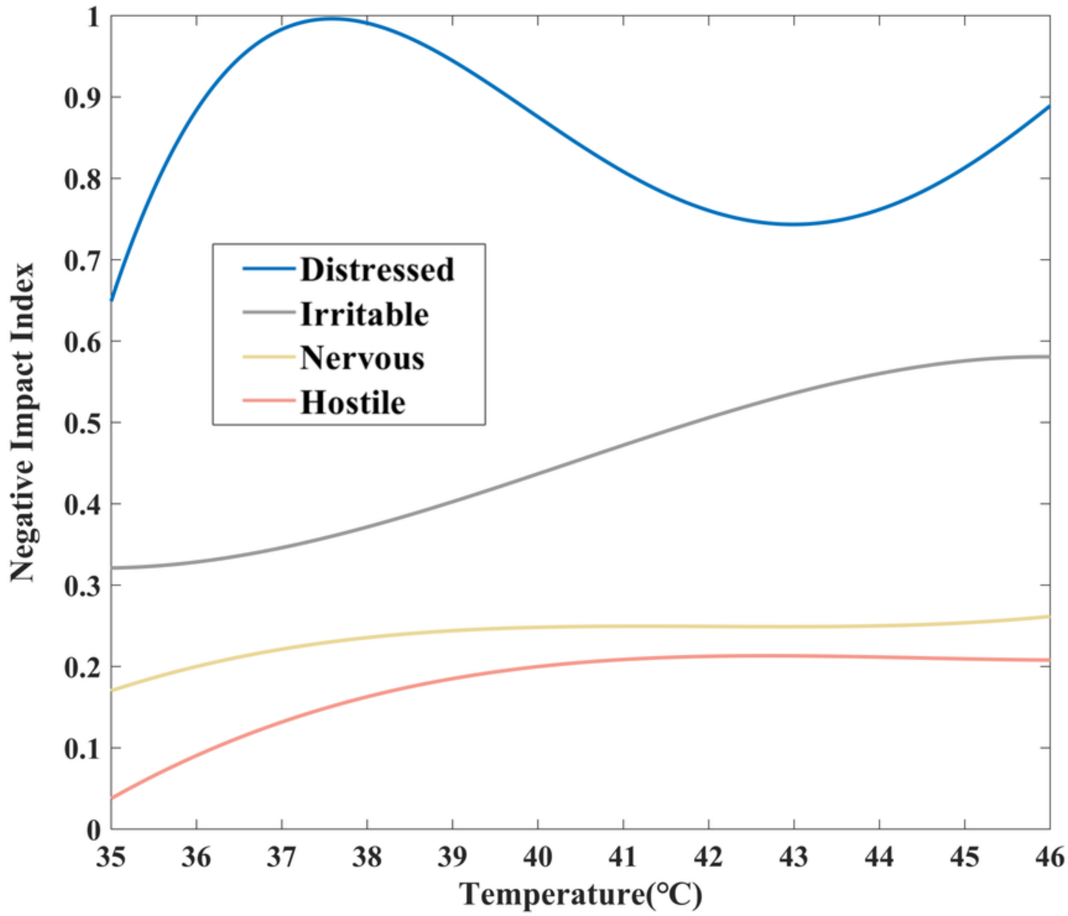

Figure 8

Difference in the effects of high temperatures on negative emotional elements

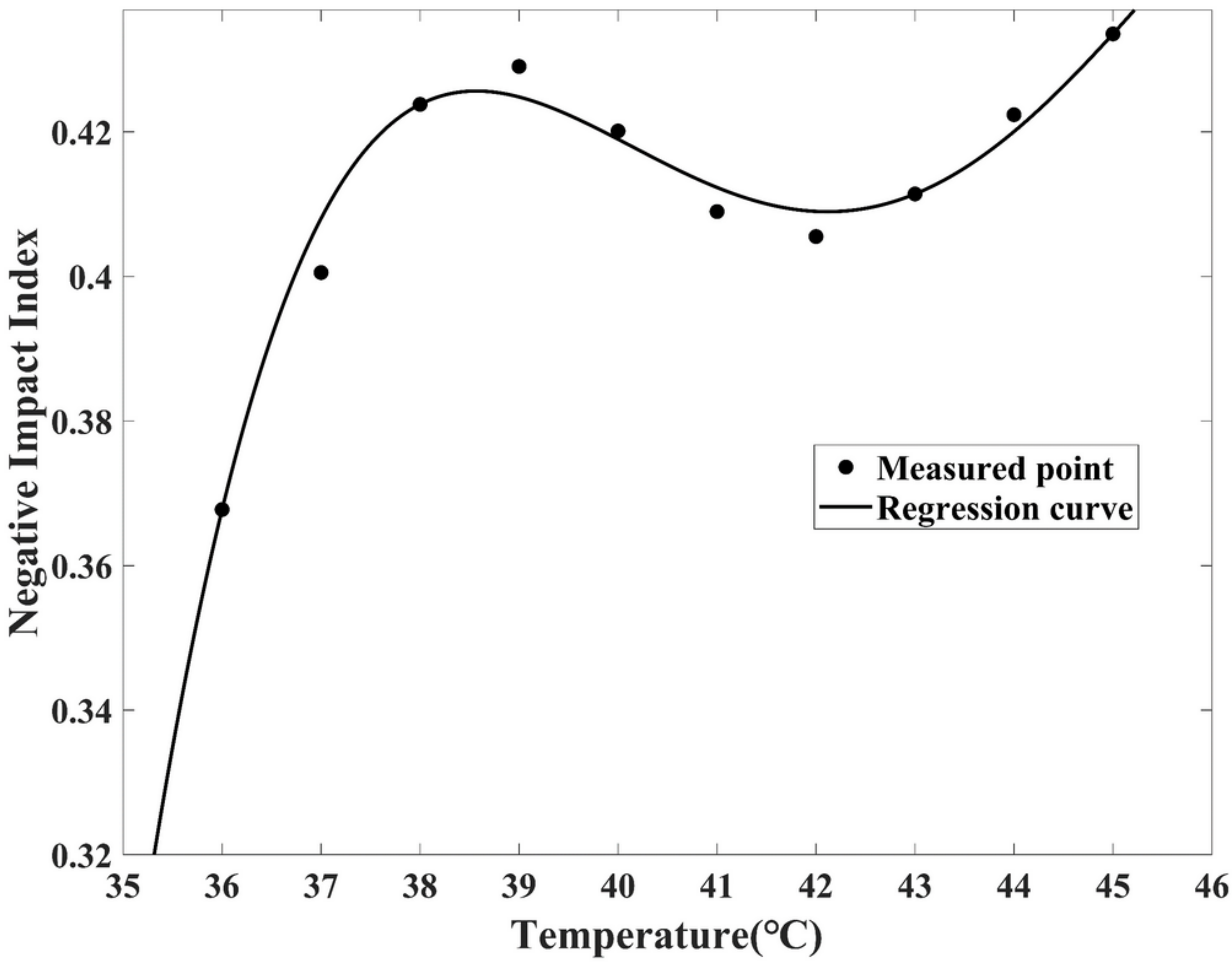

Figure 9

Combined effects of high temperatures on negative emotions

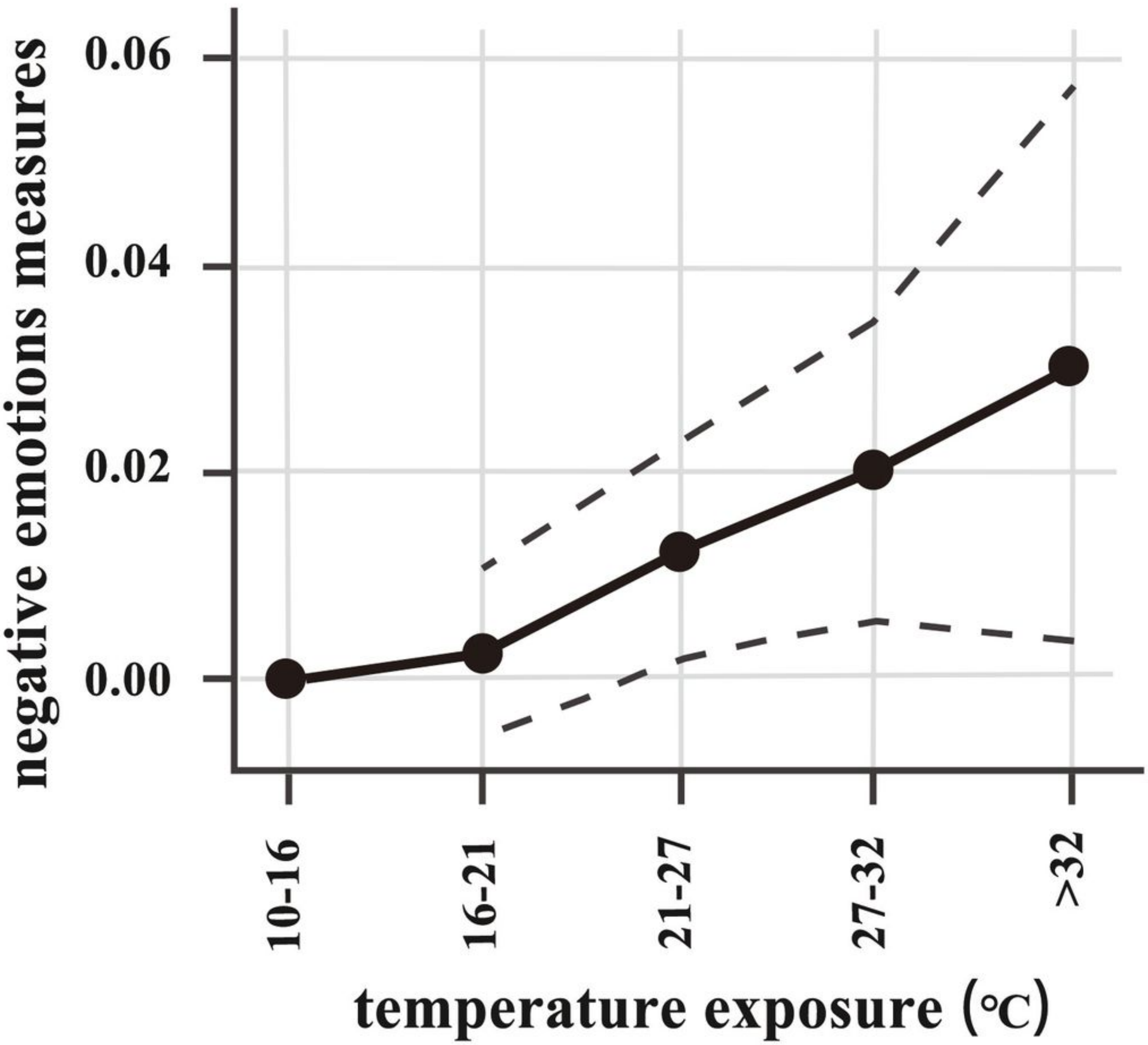

Figure 10

The effect of temperature exposure (°C) on negative emotions [18]

Supplementary Files

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- Equations.pdf