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RESEARCH ARTICLE

Effective interventions on health effects of Chinese rural elderly under heat exposure

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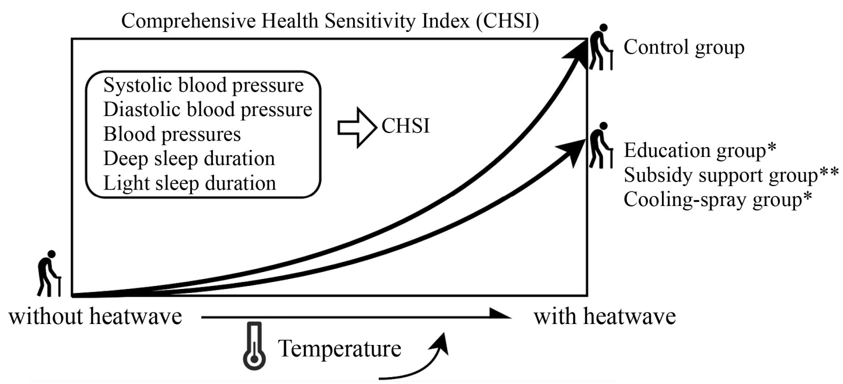
HIGHLIGHTS

- Education and subsidy were effective interventions during short-term heat exposure.
- A new index was defined to evaluate the intervention performance.
- Blood pressure and sleep duration were more heat-sensitive for the elderly.

GRAPHIC ABSTRACT



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ABSTRACT

Due to climate change, the heatwave has become a more serious public health threat with aging as an aggravating factor in recent years. There is a pressing need to detect the most effective prevention and response measures. However, the specific health effects of interventions have not been characterized on an individual scale. In this study, an intervention experiment was designed to explore the health effects of heat exposure at the individual level and assess the effects of different interventions based on a comprehensive health sensitivity index (CHSI) in Xinyi, China. Forty-one subjects were recruited randomly, and divided into one control group and three intervention groups. Interventions included education (Educate by lecturing, offering relative materials, and communication), subsidy support (offer subsidy to offset the cost of running air conditioning), and cooling-spray (install a piece of cooling-spray equipment in the yard). Results showed that systolic blood pressure (SBP) and deep sleep duration (DSD) were significantly affected by short-term heat exposure, and the effects could be alleviated by three types of interventions. The estimated CHSI indicated that the effective days of the education group were longer than other groups, while the lower CHSI of the subsidy group showed lower sensitivity than the control group. These findings provide feasible implementation strategies to optimize Heat-health action plans and evaluate the intervention performance.

1 Introduction

Along with global climate change, the average surface temperature has increased more than 1 °C above the pre-industrial level continuously (Watts et al., 2019; Brennan et al., 2020; Aghamohammadi et al., 2021). Heatwave is a typical extreme temperature issue and has become a potential risk to public health (Anderson and Bell, 2011; Gasparrini and Armstrong, 2011; Chen et al., 2018; Bose-O'Reilly et al., 2021). Heatwaves not only lead to death but also raise the morbidity of respiratory and cardio-vascular diseases, which contribute to the increment of mortality (Fouillet et al., 2006; Kaiser et al., 2007; Zhang et al., 2019a; Lu et al., 2021). Based on research with

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different spatial scales, it was found that the frequency of global heatwaves increased by 2.7 times every ten years (1981–2010), while the amount of extreme warming events in China increased by 6.79 days/decade (1961–2017) (Song et al., 2013; Han et al., 2020). It is convinced that the number of high-temperature days shows a decreasing trend in the central and an increasing trend in the northwest and southeast, based on an analysis of high-temperature characteristics over fifty years in China (Tan and Zheng, 2013; Ye et al., 2013). Though there are periodic fluctuations, the frequency, intensity, duration, and area of heatwave show a climbing trend by and large (Yang et al., 2021).

The elderly have been recognized as the most vulnerable people to heatwave (Cheng et al., 2018; Meade et al., 2020; Morais et al., 2021). In the past decades, the heat-related mortality of the elderly (⩾ 65 years) has increased by 53.7% (Watts et al., 2021). Notably, the heat exposure of the elderly in China has come up to 2.2 million person-days, representing some 13 additional days of heatwaves experienced (Cai et al., 2021; Watts et al., 2021). When exposed to high temperatures, people will take steps to cool themselves through sweating automatically (Pennisi, 2020). However, the elderly's poor temperature regulation ability results in an increase in their sweating threshold (Meade et al., 2020). Due to income and chronic diseases, rural residents are more likely to be affected (Huang et al., 2018). In addition, owing to low risk perception, awareness, and financial concern, it is difficult for older people to accept the heat-related recommendations, especially those over 75 years old and low-educated (Nogueira et al., 2005; Sheridan, 2007). Thus, it is a considerable challenge to alleviate the heat health risks of the elderly.

Evidence suggests that the heat health warning system and education can reduce heat-related death rates by improving residents' risk perception (Mayrhuber et al., 2018; Ban et al., 2019; Ebi, 2019; Martinez et al., 2019). The effectiveness of an intervention is mainly measured by the reductions in high temperature-related morbidity and mortality, or by the improvement in public response behavior (Masato et al., 2015; Wang et al., 2018; Matzarakis et al.,2020). However, no researchers have measured the potential impact or benefit of the actions in reducing the incidence of high temperature-related morbidity. Heart rate and blood pressure are essential signals when the physical load of human body changes. Thus, they partly explain the mechanism of temperature-related cardiovascular diseases (Kim et al., 2012; Madaniyazi et al., 2016). Sleep is another important indicator of global concern. A Chinese survey showed that temperature was not only one of the most uncomfortable, but also one of the most influential environmental factors that affect sleep (Zhang et al., 2019b; Tsang et al., 2021). Though the long-term relationships between temperature change and heart rate or, blood pressure or sleep have been figured out in previous studies, the effect of interventions on individual health is still unclear.

Along with the threat of global warming and population aging, it is challenging to struggle with high temperatures. Air conditioning usage can reduce subjective thermal discomfort but contributes to more global greenhouse gas emissions (Jay et al., 2021). Therefore, there is a pressing need to explore sustainable and effective intervention measures. However, like the warning system, the previous intervention fails to evaluate the effect at an individual scale (Takahashi et al., 2015). To the best of our knowledge, there have been few reports on the relationships between interventions and health indicators about the elderly in a realistic condition. Additionally, various heat-related influences on physical indicators make it challenging to assess the effectiveness by one metric. Thus, it is necessary to explore individual-based interventions and evaluate their effectiveness through a proper approach. We conducted an intervention experiment involving the Chinese rural elderly in 2019. Previous research has explored the intervention effect on behavior and perception, but the relationship between physical metrics and intervention is unclear (Lou et al., 2021). Specifically, the objectives of this research are 1) to characterize six metrics' variation under heat exposure; 2) to evaluate the protective effect of three interventions with a comprehensive index; 3) to explore the possibility of a sustainable intervention method. Based on the research, the governments and institutions could develop and improve a more targeted implementation to reduce heat-related health risks for the rural elderly.

2 Material and methods

2.1 Study design

Jiangsu Province is one of the provinces that suffered heatwaves with the highest frequency and intensity in China (Li et al., 2016b; Chen et al., 2017). Compared with other cities in Jiangsu, the heatwave frequency, heat vulnerability index, and daily mean stroke death in Xuzhou months are relatively high, especially in summer (Zheng et al., 2012; Chen et al., 2016; Zhou et al., 2017). Xinyi is a county-level city located in the north part of Xuzhou. As an important transportation hub in East China, with a population of 0.96 million in 2020. Based on previous studies, the heat health risk of residents is considerably higher in rural than in urban areas (Chen et al., 2015). We conducted the survey in the rural area of Xinyi city. There are over eight hundred elderly people in the selected area. With the support from the local Chinese Center for Disease Control and Prevention (Xinyi CDC), we selected one hundred elderly people by simple random sampling. Eighty of the one hundred elderly expressed the willingness to attend this study. We excluded thirtyseven elderly people with primary diseases such as hypertension, diabetes, and other chronic diseases, which make it difficult to identify the main factors of health metrics' changes. Forty-four elderly people were recruited for the following intervention study. Basic characteristics indicators were collected by face-to-face questionnaire. After controlling the variation in basic characteristics, the participants were randomly divided into control group, education group, subsidy support group, and cooling-spray group. Three participants dropped out for personal reasons during the survey and forty-one were left for final analyses. For education intervention, participants took lectures (July 21st), read heat-related materials (July 22nd), and communicated with our team members (July 23rd), respectively. Participants of the subsidy support group received 10 yuan (based on the local electric charge, the average cost of air-conditioning use for one day is about 10 yuan) each day to offset the cost of air conditioning use for five consecutive days. Cooling-spray equipment was made up of a micro pressure pump and a pipe of 15 m in length, installed 2 m high in the yard of each participant from the cooling-spray group. The equipment was set to spray 5 min every half hour from 9.am to 5.pm to cool the external environment house.

This study used the 90th percentile daily maximum temperature as a relative threshold to define a heat wave (Guo et al., 2017; Wang et al., 2021). The 90th percentile temperature in Xinyi is 32 °C. The survey lasted from 17th July, 2019 to 25th July, 2019. To characterize the variation after the intervention, we defined the period before intervention (17th July–20th July) as period 0, and each day of intervention from 21st July to 25th July as day 1, day 2, day 3, day 4, and day 5, respectively. The data in period 0 represented the baseline of the participants. Three intervention groups were assigned to receive the education, subsidy, and cooling-spray from day 1 to day 5, while the control group did not undergo any intervention measures throughout this survey. The content of the study design and statistical analysis is shown in Fig. 1.

The experimental protocol (202101) was approved by National Institute of Environmental Health, Chinese Center for Disease Control and Prevention. Written informed consent was obtained from all participants following a detailed description of the purpose of this study.

2.2 Health outcome and exposure measures

A wrist blood pressure monitor was used to measure the blood pressure and heart rate of the participant. The participants would sit for 3–5 minutes before monitoring to decrease the effects of activity status. Each metric was measured three times every morning during the whole period. Daily sleep duration was monitored by a smart band worn by the participant on his/her hand. The sleep duration was divided into total sleep duration (TSD), deep sleep duration (DSD), and light sleep duration (LSD) for describing different sleep states.

A portable temperature and humidity sensor (Renke, COS-04, 73 mm × 53 mm × 27 mm) was placed upper chest and used to measure individual temperature and humidity exposure data every five seconds. The sensor has a temperature accuracy of ±0.3 °C and a measurement range from −20 °C to 65 °C. The relative humidity accuracy of the sensor is ± 2% RH (www.renkeer.com). Participants were required to wear the equipment all day (0:00–24:00) from July 17th to July 25th.

2.3 Statistical analysis

Multiple measurements of the same object in different periods bring out the autocorrelation between repeated measurement data. The linear mixed-effects model overcomes the weakness that cannot be analyzed when the response variable has the characteristics of non-independence and heteroscedasticity. The random effect term was introduced to expand the application range of the linear model. The model was constructed using Eq. (1).

$$\begin{aligned} Y_i &= \beta_{0i} group + \beta_{1i} period + \beta_{3i} group \times period \\ &+ \beta_{ni} X_{ni} + Z_i \Gamma_i + \varepsilon_i, \end{aligned} \tag{1}$$

where Y_i represents i^{th} health metric (blood pressure, heart rate, sleep duration), *group* (control group, education group, subsidy-support group, cooling-spray group), *period* (before the intervention, each day of intervention) and the interaction items between *group* and *period* were fixed effects, X_{ni} are different matrixes of other additional covariates (personal temperature exposure, relative humidity, age, sex, education, BMI, whether drinking, whether smoking), β_{ni} is the parameter vector of additional covariates, Z_i is the design matrix of random effects (participant's id), Γ_i is the parameter vector of the random effect, and ε_i is the residual random error vector.

In this study, the "lme4" software package in R software was used to construct a mixed effect model to evaluate the impact of an intervention on outcome variables, including blood pressure, heart rate, and sleep duration. We fitted the models with or without covariates respectively and compared the fit using the Akaike Information Criterion (AIC). The changes of health metrics among days were calculated based on the results of the linear mixed-effects model. The "emmeans" package in the R software was used to compare the value of metrics between intervention groups and control groups from day 1 to day 5, and calculate the differences.

2.4 Comprehensive health sensitivity index (CHSI)

Each physical metric could reflect the body's adjustment to temperature change. However, most physical metrics, like blood pressure, have a threshold in medicine (Wei

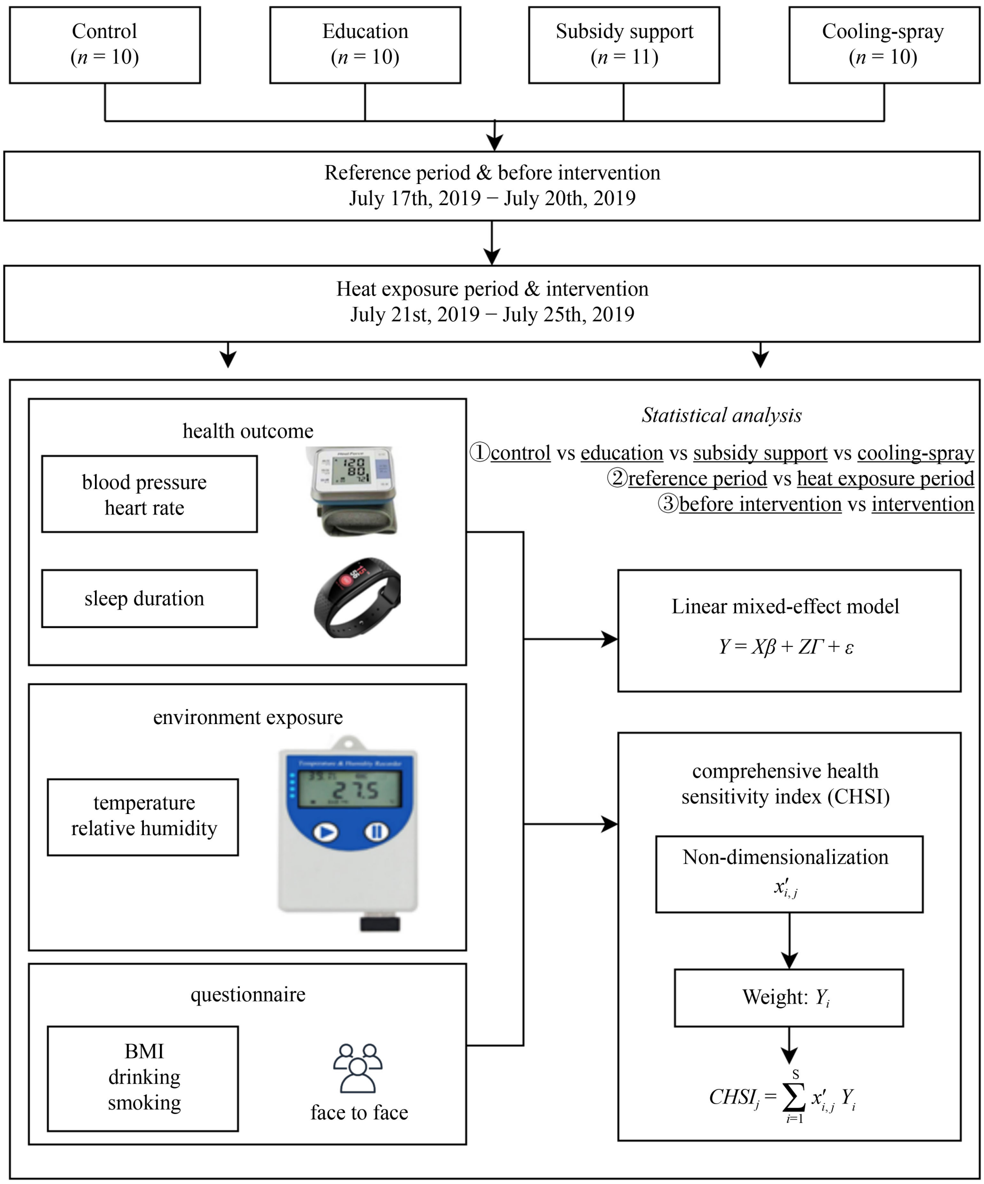

Fig. 1 Flowchart of the methodology.

et al., 2021). When the metrics are within the threshold, a person is considered at a low risk to get an unhealthy outcome. When extreme weather events such as heatwaves occur, the metrics will fluctuate due to the regulation of the body, even beyond the threshold range. The changes in blood pressure, heart rate, and sleep duration explain the sensitive level from different aspects, respectively. All changes should be taken into consideration when choosing a better intervention. However, the dimension and the contribution to health effects vary from each indicator. Anyone indicator cannot be used to select a better intervention solely, which contributes to the bias of results. Therefore, we attempted to characterize the sensitivity level of residents to temperature changes through the fluctuation of metrics, defining it as a comprehensive CHSI. When the health index fluctuates greatly, it is considered that the residents' health sensitivity is high. In this study, CHSI was made up of heart rate, blood pressure, and sleep duration.

The specific steps are as follows:

(1) Non-dimensionalization data processing metric:

$$x'_{i,j} = \frac{\left|x_{i,j} - x_{i,0}\right|}{x_{i,0}}. \tag{2}$$

The variable $x_{i,j}$ represents the average data of the i^{th} metric for each group on the j^{th} day of the intervention. $x_{i,0}$, which is the mean value of the i^{th} metric in period 0. $x'_{i,j}$represents the data of the i^{th} metric on the j^{th} day during intervention after non-dimensionalization processing.

(2) Calculating weights for each of the components of

the CHSI, Y_i

We aggregate the metrics for the first time to highlight the importance of each indicator at different moments in time (Eq. 3), in which the weight Ω_i is determined by the AHP (Analytic Hierarchy Process). The time vector w_j was calculated by Eq. 4. The second aggregation was performed by inducing the TOWA operator in terms of time (Eq. 5) (Qu et al., 2010; Huang et al., 2020). The second aggregation was based on the first weight and then highlighted the role of time. Then Eq. 6 was used to calculate the metric's weight Y_i.

$$b = \sum_{i=1}^{5} x'_{ij}\Omega_i, \tag{3}$$

$$\begin{cases} \max\left[-\sum_{i=1}^{n} w_i \ln w_j\right] \\ \begin{cases} \lambda = \sum_{j=1}^{n} \frac{n-j}{n-1} w_j, \\ \sum_{j=1}^{n} w_j = 1 \\ w_j \geq 0, n = k \end{cases} \end{cases} \tag{4}$$

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$$X_{ij} = F(\{1, X_{i1}\}, \{2, X_{i2}\}, \cdots, \{5, X_{i5}\}) = \sum_{j=1}^{5} w_j b, \tag{5}$$

$$Y_i = \frac{\Omega_i \sum_{1}^{5} w_j x'_{ij}}{X_{ij}} \tag{6}$$

where b is the evaluation value of each evaluation object in the specific period; Ω_i is the subjective weight of the i^{th} metric; λ is the "time degree"; $W = (w_1, w_2, \ldots, w_5)^T$ is the time weight vector; X_{ij} is the result of the second aggregation;

(3) Calculation of CHSI

$$CHSI_j = \sum_{i=1}^{5} x'_{i,j} Y_i, \tag{7}$$

where $CHSI_j$ represents the comprehensive result of each day during the intervention period.

3 Results

The maximum air temperature (AT_{max}) in each period and the average individual exposure temperature of each group were in Table S1, and the air temperature range has been showed in Fig. S1. The AT_{max} of the intervention period (July 21st to July 25th) was higher than 32 °C, which means that the intervention was conducted during a heat wave. Compared with the control group, a decreasing trend has been observed in personal average

Table 1 Baseline characteristics of the study population by groups

Characteristics	Control group	Education group	Subsidy support group	Spray-cooling group	*P*-value
Number	10	10	11	10	–
Sex					
Male	4	3	5	4	0.910
Age[a)]	57.9±6.57	58.4±6.42	58.8±6.66	60.1±7.40	0.881
Education					
Low level	6	6	8	6	0.917
Medium level	4	4	3	4	
Family annual income per capita(yuan)[a)]	15 330±9777	15 690±8442	13 982±4020	15 050±7920	0.967
Air-conditioning ownership					
Yes	8	9	10	8	0.825
No	2	1	1	2	
Physical condition					
Moderate	3	4	3	4	0.894
Healthy	7	6	8	6	
BMI[a]	24.30±3.56	24.11±1.75	24.94±3.36	21.97±2.62	0.160
Smoking					
Yes	6	4	4	6	0.600
No	4	6	7	4	
Drinking					
Yes	1	2	2	3	0.750
No	9	8	9	7	

Note: a) The format of data in the table is Mean ± standard deviation. "Moderate" physical condition means slightly worse than healthy.

temperature in intervention groups during the heatwave. Table 1 showed a detailed summary of all participants. The age of each group ranged from 57.9 to 60.1, and the proportion of air conditioning users was higher than 80% in each group. No significant differences have been observed in baseline characteristics among groups as shown in Table 1 ($P > 0.05$).

3.1 Control group

The changes in blood pressure have been displayed in Figs. 2(a) and 2(b). The Diastolic Blood Pressure (DBP) of the control group showed an insignificant increase in the first four days and the maximal level was 3.33 mmHg. The Systolic Blood Pressure (SBP) in the control group significantly increased on day 1 and day 2, rising by 5.33 mmHg (95%CI: 3.38–7.30; P = 0.01) and 4.92 mmHg (95%CI: 2.74–7.09; P = 0.02) 5.33 mmHg (95%CI: 1.05–9.60; P = 0.02), respectively. After day 3, the changes of SBP became more moderate.

The Heart Rate (HR) level kept rising across the intervention, with the daily increase ranging from 0.37 beats/min to 1.45 beats/min (Fig. 2(c)). The increase was the greatest on day 1, while the highest daily ambient temperature increased sharply from 31.6 °C (July 20th) to 34.7 °C (July 21st). However, there was no significant difference between groups or periods.

Total sleep duration (TSD), made up of deep sleep duration (DSD) and light sleep duration (LSD), decreased slightly during the intervention period, with a daily decline of 0.06 h to 0.26 h (Fig. 2(d)). DSD changed significantly in the first 3 days from −0.48 h (95%CI: −0.61, −0.34; P=0.00) to –0.36 h (95%CI: −0.51, −0.21; P = 0.01) and −0.25 h (95%CI: −0.37, −0.12; P = 0.05). LSD showed a slight and insignificant upward trend during the intervention period.

3.2 Intervention groups

The DBP of the education group changed slightly during the whole period, while the DBP of the cooling-spray group and the subsidy support group had a similar increasing trend as the control group (Fig. 3). There was no significant difference observed in DBP in these three groups during the intervention. In the education group and the subsidy support group, SBP stayed at a relatively stable level throughout the entire period. The trend of SBP of the cooling-spray group was similar to that of the control group. There was a significant increase of 3.18 mmHg (95%CI: 1.73, 4.63; P = 0.03) and 3.34 mmHg (95%CI: 1.76, 4.93; P = 0.04) on day 1 and day 2 in SBP for the cooling-spray group. The SBP level then gradually declined and became steady. Figure 4 shows the differences in blood pressure between the control group and different intervention groups. Compared with the control group, SBP of the education group was 7.94 mmHg (95%CI: 5.36, 10.52; P = 0.02) and 8.25 mmHg (95%CI: 2.54, 7.78; P = 0.01) lower on day 1 and day 2, respectively.

The changes in HR in the cooling-spray group were consistently greater than baseline across all time points, but the trends were not consistent in the subsidy or education groups (Fig. 5). The changes in HR in the subsidy group began to decrease after day 3. Differences in HR between the control group and intervention groups ranged from −5.05 beats/min (subsidy support group on day 1) to −0.91 beats/min (cooling-spray group on day 5) (Fig. S2).

Changes in DSD of the education group and the subsidy support group even showed a slight increment (Fig. 6). Changes in DSD of the cooling-spray group fluctuated during the intervention period, with the largest reduction being –0.21 h (95%CI: –0.31, 0.11; P = 0.05)

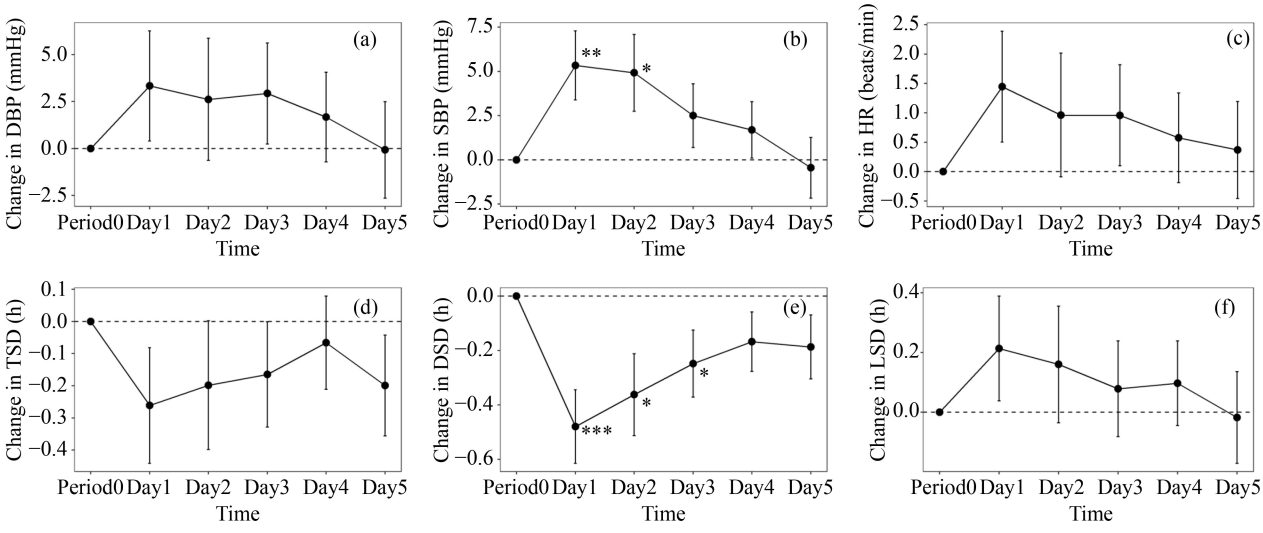

Fig. 2 Changes in different health metrics of control group from baseline (period 0) (*P < 0.05, **P < 0.01, ***P < 0.001, compared with period 0, the error bars represent estimate value ± SE).

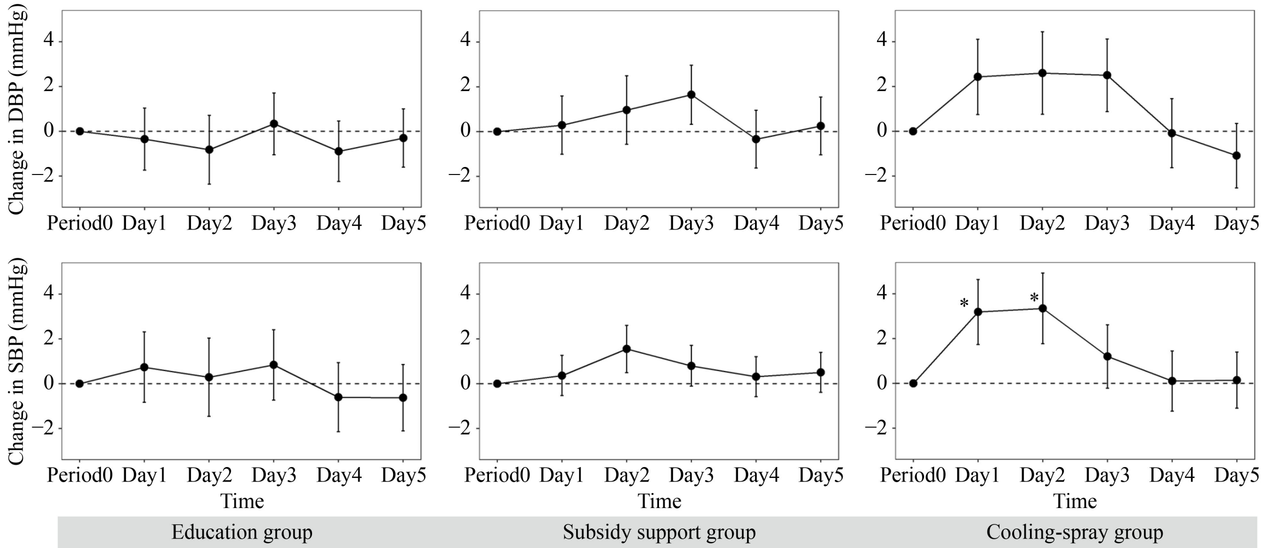

Fig. 3 Changes in blood pressure of three intervention groups from baseline (period 0) (*P < 0.05, compared with period 0, the error bars represent estimate value ± SE).

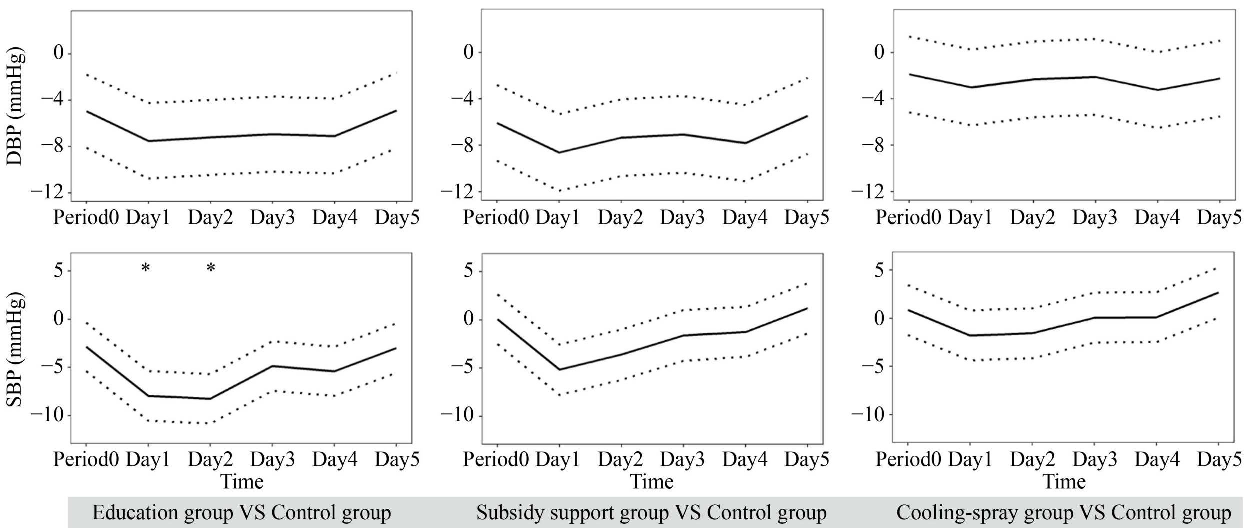

Fig. 4 Difference in blood pressure between intervention groups and control group (*P < 0.05, ** P < 0.01, compared with control group, the error bars represent estimate value ± SE).

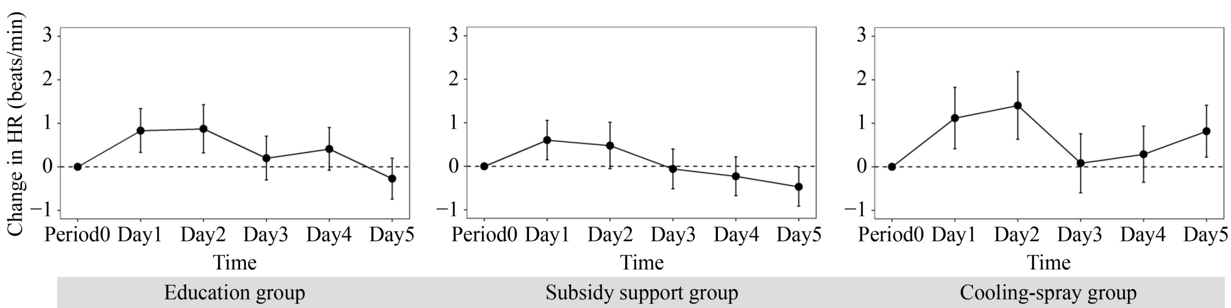

Fig. 5 Changes in heart rate of three intervention groups from baseline (period 0) (The error bars represent estimate value ± SE).

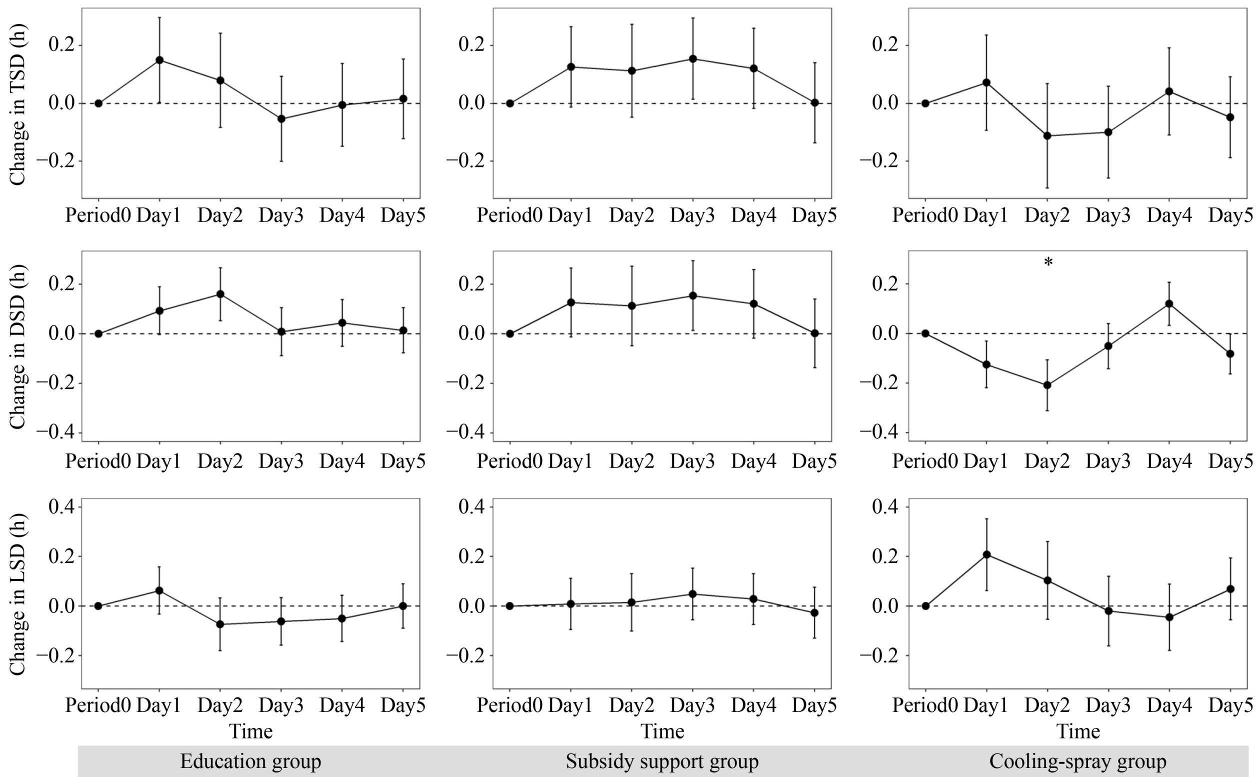

Fig. 6 Changes in sleep duration of three intervention groups from baseline (period 0) (the error bars represent estimate value ±SE).

on day 2. Analyses of DSD difference between groups in each period (Fig. S3) showed that the DSD levels of the education and subsidy support groups were higher than that of the control group in the five days of intervention. The DSD difference between the education group and the subsidy support group was statistically significant only on day 1.

Changes in LSD were minor in three intervention groups, ranging from −0.07 h to 0.06 h in the education group, from −0.03 h to 0.05 h in the subsidy support group, and from −0.04 h to 0.21 h in the cooling-spray group. As a result, changes in TSD of the subsidy support group maintained a continuous increment, while changes in the education group and the cooling-spray group rose in the first few days and then declined. When comparing TSD between groups, TSD in the cooling-spray group was lower than the control group, while TSD in the education and subsidy support group were much higher. However, no significant between-group difference was observed in TSD and LSD during the experiment.

3.3 Comprehensive CHSI

Weights of health metrics have been listed in Table 2. On day 1, the score of CHSI in control group (6.93) was significantly higher than education group (3.72, $P < 0.05$), subsidy support group (3.50, $P < 0.01$) and cooling-spray group (4.22, $P < 0.05$), which showed that control group had the highest health sensitivity at the start of the heatwave (Fig. 7). However, CHSI in control group declined over time. The score of CHSI decreased from 6.92 to 3.43 on day 5, indicating the human internal environment in control group had gradually reached a balance. On the second day of the intervention, the scores of the education group and the subsidy support group

Table 2 Weights of health metrics

Metrics	HR	DSD	SBP	LSD	DBP
Weight	0.3267	0.2346	0.1402	0.1402	0.1191

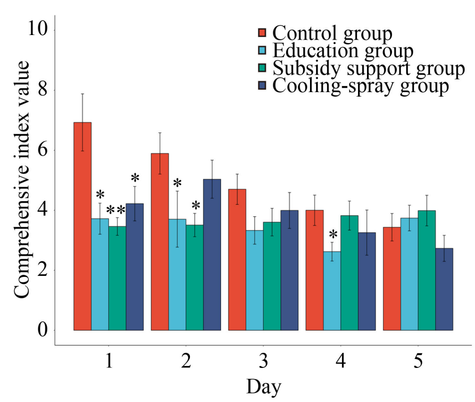

Fig. 7 Variations in comprehensive sensitivity Index in four groups along with intervention time (*$P < 0.05$, ** $P < 0.01$, compared with the control group, the error bars represent estimate value ± SE).

were still significantly lower than that of the control group ($P < 0.05$). Though there was no significant difference between control group and cooling-spray group observed, the sensitivity level of cooling-spray group was lower than control group during the experiment.

4 Discussion

Based on the comparison between period 0 and high-temperature periods in the control group, health metrics fluctuated greatly when exposed to short-term heat. There was a significant variation in SBP and DSD, which was similar to some previous findings, suggesting that the high-temperature exposure contributed to higher blood pressure and thermal comfort was an essential factor affecting sleep quality (Guo and Tang, 2015; Zhang et al., 2018; Zhou and Liu, 2018). Several studies showed that poor sleep quality might result in increased night-time blood pressure (Tamura et al., 2021). Nevertheless, the relationship between daily blood pressure and sleep quality needs further study. When exposed to high temperatures, individuals will increase cardiac output and turn on sweat glands to regulate body temperature, contributing to blood pressure variation (Pennisi, 2020). However, aging is associated with the degenerated ability of cardiovascular adjustments and fluid regulation, resulting in the elderly might take a higher risk of cardiovascular disease than young adults (Meade et al., 2020). Because of the effects of human aging on organs and tissues, the elderly have blunted vascular responses and reductions in sweat production, which leads to a limitation of heat dissipation. Trouble falling or staying asleep is another mainly heat-related physical symptom (Aghamohammadi et al., 2021). Findings from other studies also firmed that sleep duration decreased significantly because of heat exposure (Kim et al., 2012; Hendel et al., 2016). The changes in each metric reflected that the body could be stabilized gradually, consistent with the experiment conducted by Meade (Meade et al., 2020). The result of metric weight showed that HR played an essential role in the comprehensive assessment. The studies conducted by Madaniyazi et al. (2016) and Madaniyazi et al. (2016) also concluded that heart rate was correlated with heat exposure. Though an increasing trend was observed during the heatwave, there was no significant variation in this study, which was possibly due to the short duration of the experiment.

CHSI indicated that education could control the health sensitivity from day 1 to day 4. In a previous study, it is convinced that there is some mediating effect between heat exposure and heat-protection action (Ban et al., 2019). The more educated, individuals had a higher risk perception on perceived controllability, perceived concern, perceived effect, and perceived familiarity (Lou et al., 2021). The promotion of risk perception leads to a variety of alternations in heat-protection actions like increased frequency in using cooling equipment (such as air conditioning), more concern about weather changes, and reduction of the time exposed to sunlight directly. These behaviors enhanced the ability of adaptation to heatwave from psychological and physical aspects and relieved the influence of heatwave (Ban et al., 2019). Besides, a study in Licheng showed that education could be considered a worthwhile investment for rural areas than urban areas in the prevalence of heat-related illness (Li et al., 2016a). These studies were content to our results, improving the reliability of CHSI.

The results of CHSI showed the effectiveness of subsidy support as well. It was found that rural individuals preferred to use fans than air conditioning because of economic issues, which can be solved by subsidy support to a great extent (Wu et al., 2020; Lou et al., 2021). A previous study has shown that subsidy support group was more likely to do home cooling practices after intervention when comparing adaptive behavioral responses in groups (Lou et al., 2021). In this circumstance, the willingness and the frequency of using air conditioning increased. As a result, the individual ambient temperature had been reduced to a comfortable level by the usage of air conditioning, which brings about a declined effect of the heatwave on health. However, the effects of subsidy support were significant in the first two periods. One of the reasons could be the limited effects on perception. It is reported that the subsidy support had no significant effect on perceived effect (Lou et al., 2021). Besides, we did not conduct an inquiry of the willingness to pay before the experiments. Therefore, the amount, frequency, and form of the subsidy might be further explored to break the limits.

Compared with education and subsidy support, the intervention effect of the cooling-spray is relatively limited. The reasons could be speculated as follows: 1) limited coverage area. The equipment was installed in the resident's yard, which means it would be useless when the resident leaves home. 2) limited effect. The outdoor temperature reduction was difficult to be conveyed to indoor. Therefore, the effect of indoor temperature reduction, as well as human thermal comfort, will be limited, when the resident stays in the house. 3) ventilation. Because of the material and the structure of the wall, the yard's ventilated condition was limited. It is reported that fans can be effective as air-conditioning, particularly in humid conditions (Pennisi, 2020). Thus, the third reason is that we did not create any wind in the yard, though the humidity had been increased by the equipment. Despite the fact that the air conditioning has an excellent temperature reduction ability, the environmental problems caused by the equipment cannot be regardless (Watts et al., 2021). Therefore, it is necessary to explore another economical and environment-friendly method to fight heatwaves.

This study has several notable strengths. First, the study explored the health effect of heat exposure among rural elderly from multiple dimensions, and found SBP and DSD were the most sensitive health metrics, providing ample evidence for the elderly group to take protective measures. Second, a comprehensive health sensitive index was defined, enabling cautious causal inferences to be drawn about the efficacy of the intervention program. The CHSI also provides a transferrable research framework for other areas' intervention and health-related studies. Third, better effectiveness of education and subsidy support provides sufficient and novel evidence for policy designation.

There are still several limitations in our study. First, the number of subjects in our sample group is relatively small, resulting in a limited number of socioeconomic and demographic categories for analysis. From the perspective of verifying the health effects of an intervention, ten subjects in each group are sufficient (Deng et al., 2020). For fundamental research, a larger number of subjects are required for future experiments. Secondly, the information on occupation and air conditioning use was not collected in the questionnaire; therefore, we cannot further analyze the effect of these two factors on physical metrics. Thirdly, the selected participants connected with the local CDC before might be more concerned about their health. Besides, they have been screened by healthy conditions, limiting the sample's representativity. Next, metrics in period 0 represents the average level of metrics without heat exposure, which means that the potential variations during period 0 might have been ignored. Meanwhile, it is difficult to link intervention with specific health endpoints because of the time limitation. Though these metrics are significantly associated with heat-related diseases, further studies should be conducted to confirm the clinically relevant outcomes of interventions.

5 Conclusions

This study explored effective intervention methods on an individual scale, which supplements the intervention effect from physiological dimension and further validates the results of our previous research. It was found that short-term heat exposure would make effect on blood pressure, heart rate, and sleep duration. Under high temperatures, SBP and DSD were significantly affected in the first two days. For rural elderly, these effects could be efficiently reduced by education, subsidy support, and cooling-spray. Though cooling-spray was not the best method to prevent heat health risk due to its limitation in coverage area and effects, it is deserved to optimize the equipment for its low carbon emission. A comprehensive health sensitivity evaluation method was proposed to assess the effectiveness of interventions. Compared with previous studies, CHSI was identified as a more practical and propagable approach in health effect assessment. The results indicated that older people should pay more attention to their blood pressure and sleep to prevent themselves from heat-related illnesses. Education and subsidy support made it possible for government and community to provide the vulnerable groups with more targeted help. These findings will provide references for researchers who further investigate the optimal strategies to reduce the health risk of human heat exposure.

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