

The Association of Temperature Variability With Blood Pressure in Southern China: a Series of Cross-sectional Studies in Guangdong Province, China

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Research

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Abstract

Background: Numerous studies have found a positive relationship between temperature variability and mortality, but few studies regarding the effects of temperature variability on blood pressure (BP) are available.

Objective: To investigate the effects of temperature variability on BP in Guangdong province, southern China.

Methods: Data on Meteorology and BP in Guangdong Province from 2004 to 2015 were collected from Guangdong Provincial Center for Disease Control and Prevention. There were 38088 participants aged 18 years and over. The generalized additive model (GAM) was used to estimate the relationship between temperature variability and BP after adjusting for confounding variables.

Result: Our study found that there was a significant positively correlation between temperature variability and systolic blood pressure (SBP), and the estimate increase with the increment of exposure days in total population. The highest estimate was found at 7 days lag with increased 0.497 mmHg of SBP (95%CI: 0.335–0.660) for a 1 °C increase of TV0-7. There was insignificant association between temperature variability and diastolic blood pressure (DBP). The effects of temperature variability on BP among subpopulations with different hypertension statuses were various, and the estimates of Temperature variability with different exposure days on SBP were all higher in known hypertensives than that in normotensives.

Conclusion: There was a significant association between temperature variability and SBP in Guangdong province with various effects for different populations. Our findings provide evidence that temperature variability is an independent risk factor for SBP changes, and temperature variability should be considered in hypertension clinic management and epidemiological survey.

1 Introduction

Global burden of disease study has reported that cardiovascular disease is the main cause of mortality and morbidity in the world [1]. Hypertension is one of the strongest risk factors for cardiovascular diseases [2]. Globally, approximate one in four adults has hypertension, and the number of people with hypertension is increasing with population rise and aging, especially in developing countries [3]. In China, there were about 244.5 million people who had hypertension in 2015 [4], and hypertension was also the primary risk factor contributing to deaths and disability adjusted life years (DALYs) in 2017 [5]. Though Chinese government has carried out lots of preventive measures against hypertension in recent years, the incidence of hypertension is still increasing, especially in young population. Therefore, hypertension still was a major public health problem in China.

There are various risk factors associated with hypertension such as unhealthy lifestyle, individual characteristics, hypertension family history [6, 7]. In the context of climate change, both temperature and

temperature variability used as to project indicator is increasing in the end of 21st century [8], and the relationship between air temperature and blood pressure (BP) has received much attention [9, 10]. Generally, ambient temperature is negatively associated with BP. Temperature variability includes diurnal temperature range (DTR), temperature change between neighboring days (TCN), and temperature variability within different exposure days (TV0-n). However, the evidence on the associations between temperature variability and BP are limited and inconsistent. For instance, Zheng et.al found that DTR was positively associated with SBP, and negatively associated with DBP in northwest China [11]. However, Lim et.al found that BP had null associations with DTR in Seoul, Korea [12]. Additionally, the two studies just focused on DTR that only represents temperature change within one day. Therefore, it is unknown whether temperature variability within different exposure days has various association with BP. Thirdly, the research sites in the two studies were in high latitude and temperate areas [11, 12], and it is necessary to conduct more studies in different climate zones to better understand the spatial heterogeneity of the effects of temperature variability on BP.

In order to fill the knowledge gaps mentioned above, we collected data from a series of cross-sectional surveys conducted during 2004–2015 in Guangdong Province of China to explore the associations of temperature variability within different exposure days with BP in a subtropical region. Our findings will provide insights on the impacts of temperature variability on BP and evidence on the clinical management of hypertension for health professionals in the community health center.

2 Materials And Methods

2.1 Study design and participants

Guangdong province, located in southern China, has a developed economy and a large population. The population in Guangdong province is about 126 million according to the seventh population census of China in 2020 [13]. The area has a subtropical monsoon climate with plenty of sunshine and precipitation. We collected data from surveys on the risk factors of noncommunicable diseases from Guangdong province in 2004, 2007, 2010, 2013 and 2015. These surveys conducted by Guangdong Provincial Center for Disease Control and Prevention, and in order to understand the prevalence of major chronic disease and their risk factors in Guangdong province, China.

Details of those surveys were described elsewhere [14–16]. Similar study designs and methods were used to all surveys implemented in 2004, 2007, 2010, 2013 and 2015. Stratified multistage cluster sampling with probability proportional to size was used to obtain research objects. First, 21 survey site including cities or counties in Guangdong province were randomly selected. Second, four districts or townships from each survey site were chosen; Third, three streets or villages constituted at least 50 households from each district or township were chosen; Fourth, one household from each street or village was randomly sampled; Finally, one participant aged ≥ 18 years was selected using the Kish grid method from each selected household. When the selected respondent did not agree to participate or there was no

people aged ≥ 18 years in the selected household, the household would be replaced by another randomly selected household nearby.

All participants received a face-to-face questionnaire interview by investigators with professionally trained experience and on-site health examination.

Questionnaires were consisted of demographics, behavioral factors and disease history. General demographics include gender (male and female), age (< 60 and ≥ 60), marital status (never married, married, and others), education level. Behavior factors include smoking, drinking and physical activity. The history of related diseases includes hypertension, diabetes etc.

Health examination main included blood pressure measurement, height and weight measurement, blood sample test. Blood pressure measured in our surveys by physicians through standardized mercury sphygmomanometers or Omron sphygmomanometers. Before measurement, participants were asked to rest at least 5 minutes, then BP was taken on the right arm 2 or 3 times 1 minute apart in a seated position. The average of readings was used for analysis. According to 2018 European society Arterial Hypertension Guidelines [17, 18], we divided participants into three different blood pressure states. Participants who have been diagnosed with hypertension by physicians before the surveys were defined as known hypertensive patients. Newly detected hypertensive patients in the surveys were defined as SBP is greater than 140 mmHg and/or DBP was large than 90mmHg but not diagnosed as hypertension before the surveys. Normotensives were defined as participants whose SBP was less than 140 mmHg and DBP was less than 90mmHg without hypertension history.

Each participant was provided a detailed introduction and explanation of this study and signed the informed consent form. Ethics was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (Ethical review code:2019025).

2.2 Meteorological data and air pollution data

Daily meteorological data during study periods were obtained from Guangdong meteorological center, including daily maximum temperature, daily minimum temperature, daily mean temperature, relative humidity, wind speed and precipitation. We connected daily meteorological data to hypertension data by climate station. If there is no climate station at survey sites, the nearest weather observation station will be selected. The air pollution data during 2013–2015 were collected from Guangdong Environmental Monitoring Center, including daily PM_{10} , SO_2 , and O_3 . We linked air pollution data to hypertension data through each individual's districts/counties. Similarly, if there is no air pollution station at survey site, the nearest observation station will be selected.

2.3 Statistical analysis

In this study, we employed DTR and TV0-n ($n = 1-7$) to assess the BP effects of temperature variability within 1 to 8 days. DTR was defined as the difference between the daily maximum temperature and minimum temperature within a day. TV0-n was calculated by the standard deviation (SD) of daily

minimum temperature and daily maximum temperature within exposure days. For example, temperature variability within 2 days' exposure (TV0-1) was calculated as follows: $TV0-1 = SD(\text{maximum temperature}_{lag0}, \text{minimum temperature}_{lag0}, \text{maximum temperature}_{lag1}, \text{minimum temperature}_{lag1})$. Therefore, the definition of temperature variability could explain both intra-day and inter-day temperature variability, as well as the delayed effects of temperature variation [19].

BP was described as mean \pm sd, and other basic characteristics of the study sample were presented as counts or constituent ratios.

A nonlinear relationship between temperature and blood pressure was showed in previous study [20]. Therefore, the generalized additive model (GAM) was used in this study to explore the nonlinear relationship between temperature variability and BP. Since the distribution of BP in the population was approximately normal, Gaussian function was selected as the connection function in the model. Cubic spline function and three degrees of freedom (df) was chosen to fit model, and covariates included daily mean temperature, precipitation, relative humidity, wind speed, BMI, age, sex, physical activity, smoking, alcohol use, and resting time. The regression model was described as the following:

$$Y_i = \beta_0 + \beta_{tv0-n} s(X_{tv0-n}, k = 3) + \beta_{tm} s(X_{mtemp}, k = 3) + \beta_n s(X_{covariate}) + \varepsilon_i$$

Y_i refers to BP; β_0 is the overall intercept, β_{tv0-n} means coefficient of TV0-n. β_{tm} means coefficient of daily mean temperature. β_n corresponds to coefficient of covariates. $s()$ refers to penalized cubic spline function, ε_i is the residual error.

To simple identification the relationships between temperature variability and BP, we further fitted linear model to obtain the linear effect of temperature on BP by replacing the cubic spline function of temperature variability in main model with a linear term.

In addition, we further analyzed the potential modifications of individual characteristics on the effects of temperature variability on BP. The following formula was used to test the significant difference between two-point estimates. Q_1 and Q_2 were estimated effects, SE_1 and SE_2 were estimated standard errors [21].

$$(Q_1 - Q_2) \pm 1.96 \sqrt{SE_1^2 + SE_2^2}$$

In sensitivity analysis, biological information (LDL) and air pollutants (et. $PM_{2.5}$, SO_2 , O_3) were separately added to the model to test the robustness of our findings.

All the statistical analyses were performed in R software version 4.0.3 using "mgcv" packages. Two-sided statistical test was conducted, and effects of $P < 0.05$ were considered statistically significant.

3 Results

3.1 Characteristics of study sample

Table 1 shows the basic characteristics of our study sample. The study included 38,088 participants. There were 4,053 known hypertensives, 6,794 newly detected hypertensives, and 27,241 normotensives. The SBP and DBP distribution densities of subpopulations with different BP statuses were almost normal (Supplementary figure S1).

Main environmental factors in the study period were shown in Table 2. The annual average DTR was 8.0°C with the range from 1.1°C to 19.9°C. The ranges of temperature variability within different exposure days (TV0–1 to TV0–7) were similar. The largest range was from 1.0 °C to 11.5 °C for TV0-1.

Table 1
General characteristics of the study population

	Normotensives	Known Hypertensives	Newly Detected Hypertensives	Total
	N (%)	N (%)	N (%)	number
Total	27241(71.52)	4053(10.64)	6794(17.84)	38088
Sex				
male	12187(44.74)	1786(44.07)	3398(50.01)	17371
female	15054(55.26)	2267(55.93)	3396(49.98)	20717
Age(years)				
< 60	23132(84.92)	1896(46.78)	4130(60.79)	24028
≥ 60	4109(15.08)	2157(53.22)	2664(39.21)	8930
BP(Mean ± SD,mmHg)				
SBP	118.67 ± 11.07	153.02 ± 22.51	150.77 ± 15.76	--
DBP	73.97 ± 7.94	87.28 ± 13.27	88.2 ± 10.68	--

Table 2

Summary statistics on environmental factors in the study period

	Min	P ₂₅	P ₅₀	Mean	P ₇₅	Max
Mean temperature (°C)	3.6	16.2	19.2	18.7	21.5	29.9
Precipitation (mm)	0.0	0.0	0.0	3.5	0.1	166.8
Relative humidity (%)	22.0	64.0	73.0	72.3	81.0	100.0
PM _{2.5} (ug/m ³)	3.7	16.9	33.0	37.3	48.2	201.0
NO ₂ (ug/m ³)	1.9	16.7	26.3	31.8	41.2	130.2
CO (ug/m ³)	0.3	0.8	1.2	1.2	1.6	4.1
SO ₂ (ug/m ³)	1.7	8.0	14.2	18.3	26.5	108.3
DTR (°C)	1.1	5.2	7.5	8.0	10.2	19.9
TV0-1(°C)	1.0	3.5	4.6	4.4	5.9	11.5
TV0-2(°C)	1.2	3.6	4.5	4.7	5.7	10.4
TV0-3(°C)	1.3	3.7	4.5	4.8	5.6	10.4
TV0-4(°C)	1.6	3.8	4.6	4.8	5.6	10.2
TV0-5(°C)	1.8	3.9	4.6	4.8	5.6	10.0
TV0-6(°C)	1.7	4.0	4.7	4.9	5.6	9.9
TV0-7(°C)	1.8	4.0	4.7	4.9	5.7	9.7

3.2 The effect of Temperature Variability on BP

Figure 2 demonstrates the exposure–response relationships between temperature variability and SBP/DBP in total population after adjusting for confounding factors. We found that all TVs within various exposure days were positively associated with SBP, the effects of TVs on SBP seemed increase with the up of exposure days. However, all TV-DBP relationships were statistically insignificant.

Table 3 further quantifies the effects of per 1°C increase in TVs within different exposure days on BP. The effects of TVs on SBP generally increased with the increment of exposure days with the highest effect for TV within 8 exposure days (0.497, 95%CI: 0.335–0.660). In terms of the effects of TV on DBP, the estimates from DTR to TV0-4 were negative, while the effects of TV0-5 to TV0-7 were positive. However, all the effects of TVs on DBP were statistically insignificant.

Table 3
Estimated effects in BP per 1°C increase in Temperature Variability for total population

Temperature variability (°C)	Changes in SBP (95%CI, mmHg)	Changes in DBP (95%CI, mmHg)
DTR	0.064(0.009,0.120)	-0.008 (-0.041,0.026)
TV0-1	0.136(0.027,0.244)	-0.059(-0.126,0.008)
TV0-2	0.182(0.061,0.304)	-0.050(-0.123,0.023)
TV0-3	0.226(0.095,0.358)	-0.075(-0.156,0.006)
TV0-4	0.380(0.237,0.522)	-0.035(-0.121,0.050)
TV0-5	0.475(0.323,0.627)	0.015(-0.075,0.104)
TV0-6	0.484(0.326,0.642)	0.042(-0.051,0.136)
TV0-7	0.497(0.335,0.660)	0.070(-0.026,0.166)
CI, confidential interval.		

Figure 2 further shows the effects of temperature variability on BP in different subgroups with various hypertension status. For normotensives, the estimates on SBP generally increased with the increase of exposure days with the highest for TV within 8 days exposure (0.357mmHg, 95%CI: 0.245–0.469mmHg). For known hypertension cases, the estimates of TV on SBP were larger than that for normotensives, and there was also an increase trend with the increase of exposure days. For newly detected hypertensives, the estimates increased first then went down with the highest effect for TV0-4 (0.323mmHg, 95% CI:0.025-0.621mmHg). For all sub-populations with different hypertension status, the effects of all TVs on DBP were statically insignificant.

3.3 Stratified analysis

The associations between TVs and SBP varied by age and sex. For normotensives, the effects for female, population aged < 60 years were higher than male and population aged ≥ 60 years. For known hypertension patients, the estimates for male, population aged ≥ 60 years were higher than female and population aged < 60 years. For newly detected hypertensive patients, the estimates of male were higher than female, and the effect of people aged < 60 years was larger. However, the differences between male and female, population aged < 60 years and aged ≥ 60 years were insignificant. The results were shown in Supplementary figure S2 and figure S3.

3.4 Sensitivity analysis

According to the smallest mean generalized cross-validation score (Supplementary figure S4), sensitivity analysis was performed for the model of the TV within 8 days exposure by controlling for PM_{2.5}, SO₂, O₃,

Low-density-Lipoproteins respectively. In Table4, the results showed that there is no substantial change in effect estimates.

Table 4
Sensitivity analysis on the association of BP with 1°C increase in TV0-7 in total population

variables	Changes in SBP (95%CI)	Changes in DBP (95%CI)
before	0.078(-0.217,0.373)	-0.099(-0.267,0.070)
adjusted PM _{2.5}	0.069(-0.265,0.402)	-0.077(-0.271,0.116)
adjusted SO ₂	0.051(-0.261,0.363)	-0.068(-0.244,0.109)
adjusted O ₃	0.098(-0.214,0.411)	-0.083(-0.260,0.094)
adjusted Low-density Lipoproteins	0.120(-0.175,0.416)	-0.076(-0.245,0.092)
CI, confidential interval.		

4 Discussion

To our best knowledge, this is the first study to examine the effect of temperature variability (TV) with various days exposure on BP in China. Our study revealed that TVs were positively related to SBP, and the effects increased with the rise of exposure days of TV. The results suggested that TV might be an independent risk factor of SBP.

Previous studies showed that temperature variability increased the risk of mortality and morbidity [22–24]. Another study showed that temperature change between neighboring days (TCN) can increase the number of emergency department for hypertension [25]. In the current study, we found that temperature variability was positively related to SBP, which is consistent with a previous study [11]. The mechanism of temperature variability on SBP is unclear to date. The possible reason is that sudden temperature changes activate the renal-aldosterone system, increasing peripheral vascular resistance, then increased systolic blood pressure [7]. Zheng’s study showed that the effect of DTR on DBP was negative [11]. Lim’s study showed that DTR and DBP are almost irrelevant [12]. In contrast, our study found that temperature variability is negative with DBP during 0–5 days exposure and positive during 6–8 days exposure, but all the estimates are statistically insignificant. The mechanism of this phenomenon is unknown yet. It may be partly explained by the body feedback effect. In the early stage of exposure, when the SBP is slightly increased due to the influence of TVs, the strong cardiovascular function may promote blood to flow back to the atrium rapidly, reducing the amount of blood stored in the arteries, then resulting to a slight decrease in DBP; when the temperature variation is continued, the cardiovascular function was

decreased, and the peripheral resistance increase, which makes the effects are positively [7]. Although the effects of TVs on DBP were insignificant in our study, it is suggested that temperature variability maybe a potential risk of DBP. Therefore, more studies about the associations of TV with DBP are needed in the future.

We also found that the effects of temperature variability on SBP increased with the increment of exposure days of TV. This is similar to the previous studies that temperature variability increased the mortality risk with the highest estimate at TV0-7 [26, 27]. The finding suggested that temperature variability may have a cumulative effect on BP. Current early warning system mainly focuses on extreme temperature events [28], and the public underestimate the risk associated with TV. Therefore, in the prevention and clinical management of hypertension in the future, temperature variability should not be neglected.

We further found that the effects of temperature variability on BP among subpopulations with different hypertension statuses were various. The estimates of TVs on SBP were higher in known hypertensives than that in normotensives. The result is similar to Hu et al.'s study [29]. It suggested that people with hypertension were more sensitive to TVs. The mechanism may be that aortic diameter reduce and vascular wall-to-lumen ratio increase in hypertensives, which lead to be more sensitive to temperature variation for known hypertensives than for normotensives [30]. In stratified analysis, our study did not find substantial difference between male and female, or different age populations.

Our findings suggested that TV is an important risk for SBP. In terms of etiology, adaptation to environmental temperature changes can partly control the onset of hypertension, then reduce the occurrence of cardiovascular diseases. Therefore, in the prevention, control and treatment of hypertension, in addition to using antihypertensive drugs and cultivating healthy eating habits, it is also important to pay attention to TV. For instance, when the temperature rises or falls sharply, the usage of air conditioners or heaters is necessary.

Our study has some strengths. First, this is a large-scale population study. second, it is first study to examine the relationship between TV within different exposure days with BP among different populations in China. However, there are several limitations for this study. Firstly, the current study was conducted only in a subtropical region in China, which may be unable to extrapolate our results into another climate zone. Secondly, we used meteorological data from weather station to calculate TV, which inability to fully reflect personal exposure levels. Finally, there is difference in the tools for measuring blood pressure.

5 Conclusion

In conclusion, we found a significantly positive association between temperature variability with different exposure days with SBP, and the known hypertensives were more sensitive than normotensives. Therefore, the public should pay attention to TV in order to better control BP in the clinical management of hypertensives.

Abbreviations

BP: blood pressure; SBP: systolic blood pressure; DBP: diastolic blood pressure; CVD: cardiovascular disease; TV: temperature variability; GAM: generalized additive model; TV0-n: temperature variability within different exposure days; DTR: diurnal temperature range; TCN: temperature change between neighboring days.

Declarations

Authors' contribution

ML performed the statistical analysis and took the lead in drafting the manuscript and interpreting the results. JL and JH designed the study and performed the statistical analysis. GH, RM, XX, WZ, XL collected and cleaned the data. JX, TL projected administration. WM projected administration, set up the collaborative network, designed the study and revised the manuscript.

Ethics approval and consent to participate

Ethics was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (Ethical review code:2019025).

Declaration of competing interest

The authors declare no competing interests.

Consent for publication

Not applicable.

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Availability of data and materials

Meteorological data can be accessed from the Guangdong Meteorological Service (<http://gd.cma.cn/>).

The hypertension data and R code of this study are available from the corresponding author (mawj@gdiph.org.cn), upon reasonable request.

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Figures

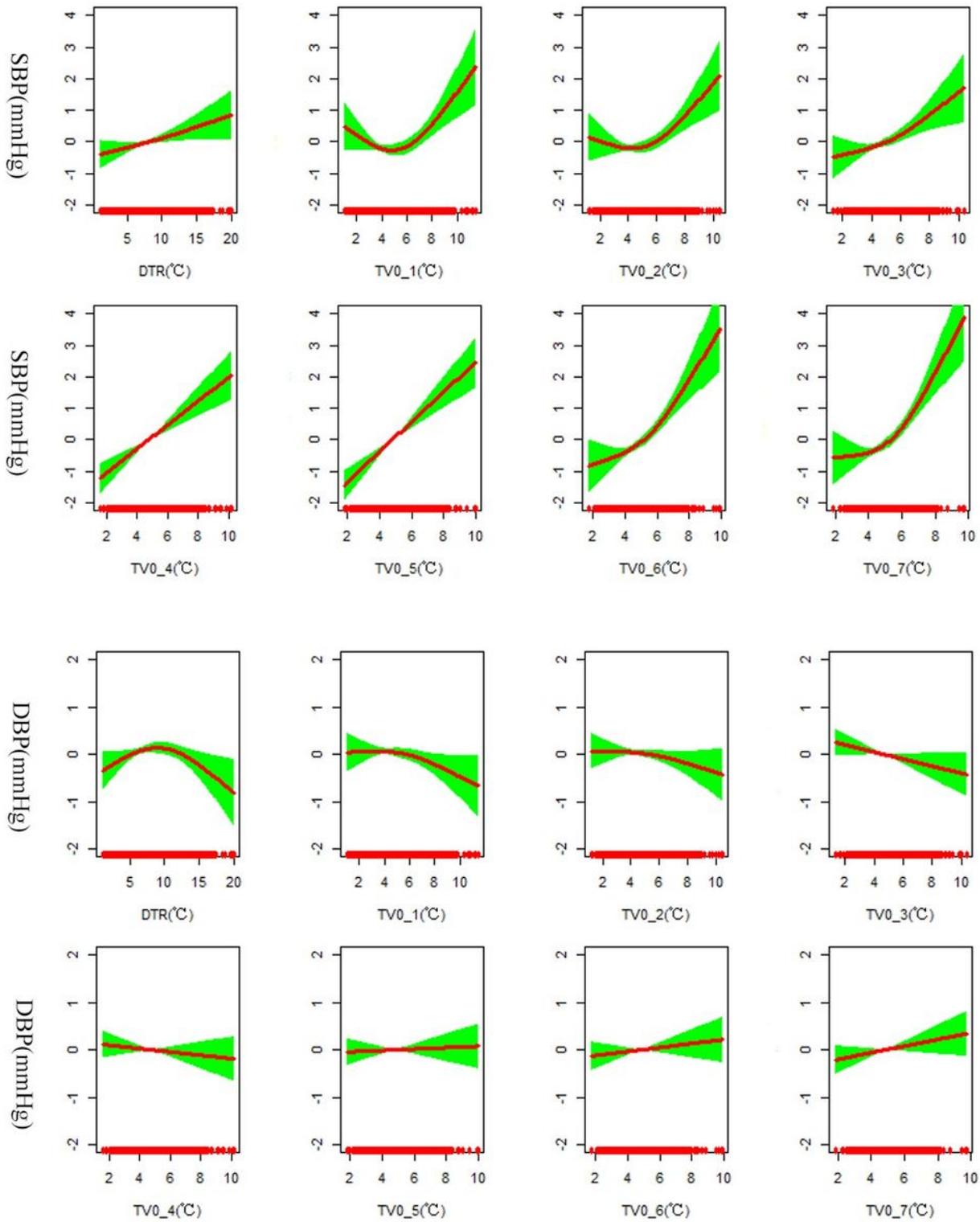


Figure 1

The exposure–response relationship between temperature variability with different exposure days and SBP/DBP in total population

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Figure 2

The exposure–response relationships between temperature variability and SBP/DBP in total population after adjusting for confounding factors.

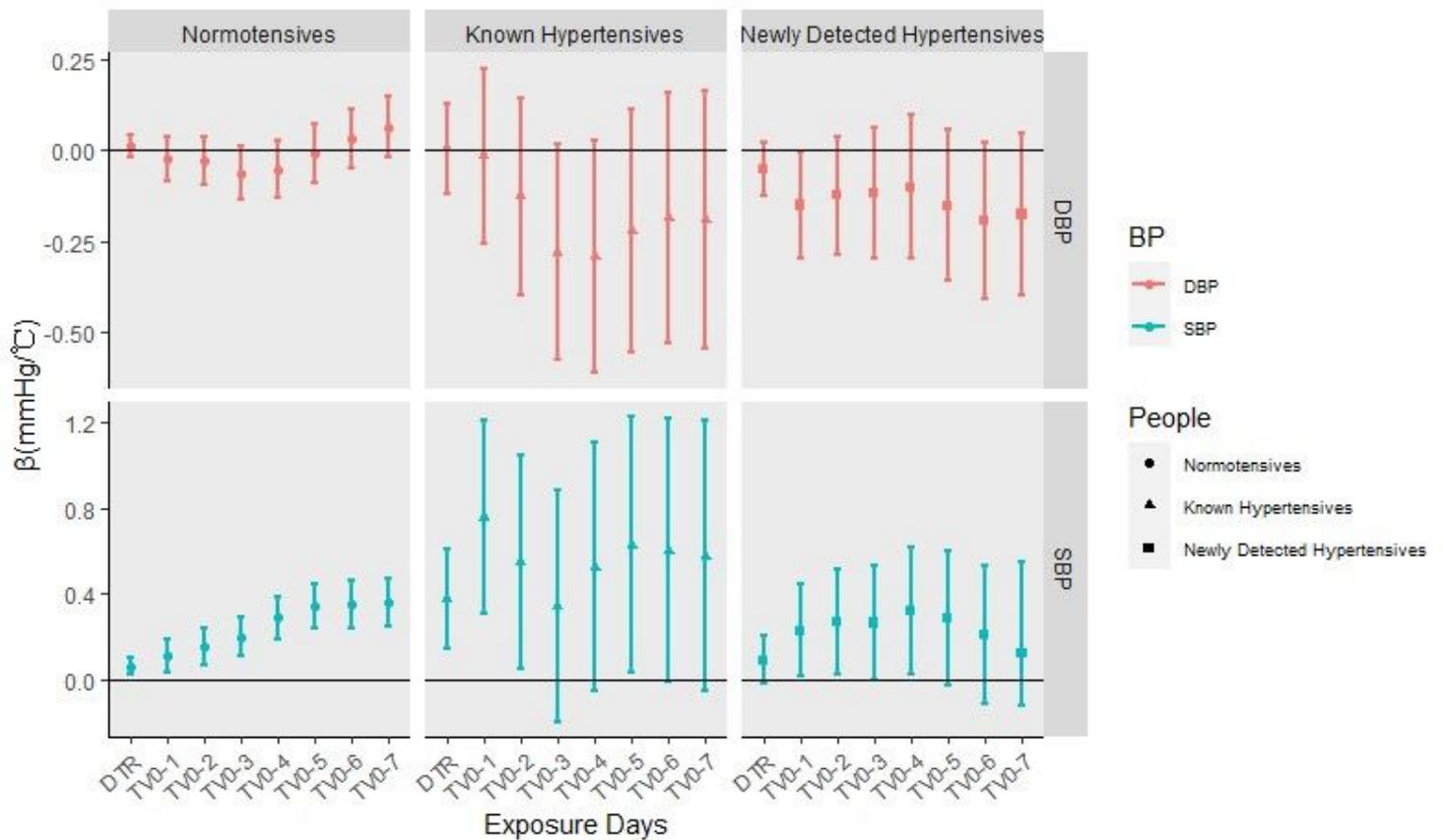


Figure 3

The BP effects of per 1 °C increase in Temperature Variability within populations with various BP status

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