Ambient temperature, seasonal variations, and blood pressure. Preliminary results from the EHUH 2 study

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Abstract

Introduction: Ambient temperature is an important determinant of blood pressure variability, although previous findings have been inconsistent. This analysis aimed to investigate the association between ambient temperature, seasonal variation, and blood pressure in the adult Croatian population.
Materials and Methods: This cross-sectional analysis included 1645 participants from the EH-UH 2 study. Ambient temperature data were provided by the Croatian Meteorological and Hydrological Service and linked to participants based on their place of residence and the date of blood pressure assessment. Blood pressure was measured according to European Society of Hypertension guidelines. Seasonal harmonic regression models and a temperature decomposition approach were used to assess the effects of short-term (within-day) and long-term (between-month) temperature variability on BP, with adjustment for age, body mass index, smoking status, and antihypertensive therapy use.
Results: Both short-term and long-term temperature components were independently associated with blood pressure values. Short-term increases in daily temperature were associated with higher systolic blood pressure values. A clear seasonal pattern was identified, with model-predicted blood pressure values peaking during January and February and reaching their lowest levels during July and August. Seasonal variability was more pronounced in coastal regions and among men aged over 50 years, in whom the peak-to-nadir difference in systolic blood pressure reached approximately 50 mmHg. Linear regression analyses demonstrated lower systolic blood pressure values with higher annual temperatures in inland regions, whereas positive associations between ambient temperature and diastolic blood pressure were predominantly observed in coastal regions.
Conclusions: Ambient temperature and seasonal variation were significantly associated with blood pressure in the Croatian adult population. These findings emphasize the importance of considering environmental factors in hypertension assessment and management.

Keywords: Blood Pressure, Hypertension, Ambient Temperature, Season, Environmental Exposure, Seasonal Variation

Sažetak

Temperatura okoliša, sezonske varijacije i arterijski krvni tlak: preliminarni rezultati istraživanja EH-UH 2

Uvod: Temperatura zraka jedan je od okolišnih čimbenika koji može utjecati na varijabilnost arterijskog tlaka, iako dosadašnja istraživanja nisu dala jednoznačne rezultate. Cilj ove analize bio je ispitati povezanost temperature zraka, sezonskih promjena i vrijednosti arterijskog tlaka u odrasloj populaciji Hrvatske.

Materijali i metode: U ovu presječnu analizu uključeno je 1645 ispitanika iz EH-UH 2 studije. Podaci o temperaturi zraka dobiveni su od Državnoga hidrometeorološkog zavoda te su povezani s ispitanicima prema mjestu stanovanja i datumu mjerenja arterijskog tlaka. Arterijski tlak mjeren je u skladu sa smjernicama Europskog društva za hipertenziju. Učinak kratkoročnih (unutar dana) i dugoročnih (između mjeseci) promjena temperature na vrijednosti arterijskog tlaka analiziran je primjenom sezonskih harmonijskih regresijskih modela i temperaturnoga dekompozicijskog modela, uz prilagodbu za dob, indeks tjelesne mase, pušenje i primjenu antihipertenzivne terapije.

Rezultati: Kratkoročne i dugoročne komponente temperature bile su neovisno povezane s vrijednostima arterijskog tlaka. Porast dnevne temperature bio je povezan s višim vrijednostima sistoličkog arterijskog tlaka. U analizi je utvrđen jasan sezonski obrazac arterijskog tlaka, s najvišim procijenjenim vrijednostima tijekom zimskih mjeseci, osobito u siječnju i veljači, te najnižima tijekom srpnja i kolovoza. Sezonska varijabilnost bila je izraženija u priobalnim nego u kontinentalnim područjima, kao i među muškarcima starijima od 50 godina, kod kojih je razlika između najviših i najnižih vrijednosti sistoličkog arterijskog tlaka iznosila približno 50 mmHg. Analiza linearne regresije pokazala je niže vrijednosti sistoličkog arterijskog tlaka uz više godišnje temperature u kontinentalnom dijelu Hrvatske, dok je povezanost temperature zraka i dijastoličkog arterijskog tlaka bila izraženija u priobalnim područjima**.**

Zaključci: Temperatura zraka i sezonske promjene povezane su s promjenama vrijednosti arterijskog tlaka u odrasloj populaciji Hrvatske. Dobiveni rezultati upućuju na važnost uzimanja u obzir okolišnih čimbenika pri interpretaciji vrijednosti arterijskog tlaka, osobito u razdobljima izraženijih sezonskih temperaturnih promjena.

Ključne riječi: arterijska hipertenzija, temperatura okoliša, sezonske varijacije

Introduction

Elevated blood pressure is a well-recognized cardiovascular risk factor with a globally increasing prevalence (1). Blood pressure is not a static parameter and changes over time under the influence of environmental, behavioral, and physiological factors (2,3). Ambient temperature is recognized as one of the major environmental determinants of blood pressure variability. The inverse relationship between ambient temperature and blood pressure is largely explained by physiological thermoregulatory mechanisms (4). Exposure to cold temperatures elicits thermoregulatory responses mediated by activation of the sympathetic nervous system, resulting in peripheral vasoconstriction and increased heart rate. These physiological adaptations increase peripheral vascular resistance, resulting in higher blood pressure during cold exposure (5). Although these responses are generally transient and compensatory in healthy individuals, they may impose greater cardiovascular stress in individuals with pre-existing cardiovascular disease or impaired cardiovascular regulation (6). Conversely, exposure to high ambient temperatures induces cutaneous vasodilation and increased skin blood flow, reducing peripheral vascular resistance and contributing to lower blood pressure. A compensatory increase in heart rate helps maintain adequate tissue perfusion during heat stress (7). These physiological mechanisms are reflected in the seasonal pattern of blood pressure observed across different populations. Although previous studies have reported inconsistent findings regarding the magnitude of these changes, seasonal fluctuations in blood pressure are well recognized (8). Nevertheless, blood pressure levels generally tend to be lower during summer and higher during winter months (9,10). One of the largest population-based studies, including more than 500,000 Chinese adults, demonstrated a seasonal variation in blood pressure, with systolic blood pressure averaging approximately 10 mmHg higher during winter than summer. The study also demonstrated a strong inverse association between outdoor temperature and blood pressure across diverse climatic regions; however, this association was substantially attenuated among participants with access to central heating during winter (11).

Similar findings have been observed using home blood pressure measurements. A nationwide study from Japan demonstrated a significant inverse association between ambient temperature and home blood pressure, with the highest values recorded in winter and the lowest during summer (12). Longitudinal evidence from the Japanese HOMED-BP study further confirmed a reproducible seasonal pattern in home blood pressure, with the highest values recorded during winter and the lowest during summer. Importantly, this seasonal variation remained evident in participants treated with antihypertensive medications, suggesting that antihypertensive therapy does not eliminate the influence of seasonal factors on blood pressure (13). Overall, previous studies consistently demonstrate seasonal variation in blood pressure, although its magnitude varies across populations and climatic settings. Croatia includes both continental and Mediterranean climatic regions, with substantial seasonal variation in ambient temperature. This climatic diversity provides an opportunity to examine the association between ambient temperature and blood pressure under different environmental conditions. Therefore, this study aimed to investigate the association between ambient temperature, seasonal variation, and blood pressure levels in the general adult population of Croatia.

Materials and Methods

EH-UH 2 study design

This cross-sectional observational study included a random and representative sample of 2048 adults from the general Croatian population who participated in the EH-UH 2 study. Inclusion criteria were age over 18 years and signed informed consent. Exclusion criteria included pregnancy or breastfeeding, terminal illness with an expected survival of less than 6 months, dementia or cognitive impairment, amputation of one or more limbs, and any condition preventing completion of the study protocol, such as paresis or limb amputation. Participants were also excluded if they decided to withdraw from the study, if the investigator considered withdrawal to be in the participant's best interest, or in cases of non-adherence to the study protocol. Data collection was performed by physicians and trained nurses using standardized epidemiological questionnaires, medical history assessments, and clinical examinations. During the home visit, participants signed written informed consent, and initial blood pressure and heart rate measurements were performed according to current guidelines. Anthropometric measurements were obtained during the outpatient visit. All study personnel underwent standardized training procedures before data collection. The EH-UH 2 study was approved by the Ethics Committee of the University of Zagreb School of Medicine (registration number: 380-59-10106-17-3931; class: 641-01/17-02/01; approval date: 13 July 2017). All participants provided written informed consent before enrolment and study procedures. The study was conducted in accordance with the Declaration of Helsinki. EH-UH 2 was organized and conducted by the Croatian Society of Hypertension and the Croatian Hypertension League and was supported by the Croatian Science Foundation (grant IP-2016-06-9033).

Patient data and methods

The EH-UH 2 study was a cross-sectional study conducted at multiple locations across Croatia. Each participant underwent a single study visit, and repeated blood pressure measurements were not available. Data collection was performed throughout the study period at different time points and locations. Ambient temperature data were obtained from the Croatian Meteorological and Hydrological Service and linked to participants according to their county of residence and the date of blood pressure assessment. For each county, data from a single meteorological station were assigned to all participants residing in that county. This analysis included 1645 participants for whom meteorological data on the day of blood pressure measurement were available from the nearest meteorological monitoring station according to their place of residence. Hypertension was defined as blood pressure ≥140/90 mmHg and/or current use of antihypertensive therapy. Diabetes mellitus was defined as the use of antidiabetic therapy and/or fasting glucose levels >7 mmol/L. Chronic kidney disease was defined according to KDIGO guidelines (14). Body weight and height were measured, and body mass index (BMI) was calculated accordingly. Abdominal obesity was defined as a waist circumference >102 cm in men and >88 cm in women. Blood pressure was measured in accordance with European Society of Hypertension (ESH) guidelines (15).

Meteorological data

Data on ambient air temperature were obtained from the Croatian Meteorological and Hydrological Service. Mean daily air temperature recorded at a height of 2 meters on the day of blood pressure measurement was used for the analysis. In addition, monthly and annual average temperatures were calculated in order to assess seasonal patterns and long-term climatic variation.

Statistical analysis

Descriptive statistics were calculated for the study population and stratified by sex. Continuous variables with non-normal distribution were expressed as medians with interquartile ranges (IQR), while categorical variables were presented as absolute numbers and percentages. Normality of distribution was assessed using the Shapiro–Wilk test. Differences between groups for continuous variables were analyzed using the Mann–Whitney U test, whereas categorical variables were compared using the Chi-square (χ^2) test or Fisher's exact test when appropriate. The association between ambient temperature and blood pressure was assessed using seasonal harmonic regression models including sine and cosine terms and ambient temperature variables, adjusted for age, BMI, smoking status, and antihypertensive

therapy use. Separate regression models were constructed for systolic and diastolic blood pressure. In addition to the basic seasonal linear model including daily temperature as a predictor, a temperature decomposition approach was applied to separate temperature into between-month (long-term climatic) and within-day (short-term daily) components. The between component reflected monthly mean temperature, while the within component reflected daily deviations from the monthly average, allowing the effects of long-term and short-term temperature changes on blood pressure to be assessed separately. Additional subgroup analyses were performed according to sex, age group, and geographic region (continental, coastal). Seasonal patterns, including winter peaks and summer nadirs in blood pressure values, were additionally evaluated across regions and demographic subgroups. Simple linear regression analyses were also performed to examine the relationship between systolic and diastolic blood pressure and different temperature measures on daily, monthly, and annual scales. Robust HC3 standard errors were used in all regression models. Residual autocorrelation was assessed using the Durbin–Watson test. No significant autocorrelation was detected for either the systolic blood pressure model (DW = 2.09, p = 0.34) or the diastolic blood pressure model (DW = 2.54, p = 0.77); therefore, no additional correction for serial correlation (e.g., Newey–West standard errors) was considered necessary. Multicollinearity among the temperature components and harmonic terms was assessed using variance inflation factors (VIF). The VIF values were 6.1 for T_within, 15.9 for T_between, 13.9 for the sine term, and 15.7 for the cosine term. The higher VIF values for T_between and the harmonic terms were expected because monthly mean temperature is inherently correlated with seasonal harmonic functions. Therefore, all variables were retained in the model to account for seasonal variation. All statistical analyses were performed using R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria). A two-tailed p-value <0.05 was considered statistically significant

Results

A 1645 participants with complete meteorological data matched to the date of office blood pressure measurement were included in the analysis. Of these, 937 (57.0%) participants resided in inland regions and 645 (39.2%) in coastal regions, while regional classification was unavailable for 63 participants. The baseline characteristics of the participants are presented in Table 1. The median age did not differ significantly between men and women. Men had significantly higher body mass index, waist circumference, and daily sodium intake compared with women. The prevalence of hypertension, diabetes, and smoking was higher among men, whereas no significant sex difference was observed for dyslipidemia. Antihypertensive medication use was slightly more frequent among men. The association between temperature variability and blood pressure values was assessed using multivariable regression models adjusted for age, gender, body mass index, smoking status, and use of antihypertensive therapy. First, the overall effect of mean daily temperature was analysed, which demonstrated a clear seasonal pattern in blood pressure variability. Subsequently, a temperature decomposition model was applied, separating temperature exposure into two components: the within-day effect and the between-month effect. Both components showed independent associations with changes in blood pressure values. Short-term increases in daily temperature (within component) were associated with higher blood pressure levels, with an increase of approximately 0.9 mmHg in systolic blood pressure for each 1°C increase in temperature. The between-month component was positively associated with both systolic and diastolic blood pressure. For each 1°C increase in mean monthly temperature, systolic blood pressure increased by approximately 0.8 mmHg, while diastolic blood pressure increased by approximately 0.3 mmHg. The seasonal regression model predicted peak blood pressure values during January and February and the lowest values during July and August (Figure 1). Average monthly systolic blood pressure values according to gender and geographic region are presented in Table 2.

Seasonal blood pressure variability was more pronounced among participants living in coastal regions than among those living in inland areas. When stratified by gender, this difference was more evident in men, while women had smaller and more stable seasonal fluctuations. These changes were most pronounced among men aged over 50 years, in whom the difference between peak and nadir systolic blood pressure values was approximately 50 mmHg, compared with about 23 mmHg in the overall study population.

Simple linear regression analyses showed different associations between ambient temperature and blood pressure across coastal and inland regions. In inland regions, higher annual mean temperature was associated with lower systolic blood pressure values, with a decrease of approximately 7–12 mmHg per 10°C increase in temperature. For diastolic blood pressure, positive associations with ambient temperature were observed mainly in coastal regions. Diastolic blood pressure increased by approximately 3.0 mmHg per 10°C increase in daily mean temperature and by 1.8–2.7 mmHg per 10°C increase in monthly and annual mean temperatures. Similar associations were observed in the overall study population, although their magnitude was smaller.

Discussion

In this nationally representative sample, blood pressure values followed a clear seasonal pattern, with higher levels during winter and lower levels during summer. The greatest seasonal variability, characterized by the highest blood pressure levels during winter and the lowest during summer, was observed in men aged over 50 years living in coastal regions. The seasonal model suggested higher blood pressure values during the winter months, par-

ticularly in January and February, and lower values during the summer months, especially in July and August, which is consistent with findings reported in other populations (16,17). In addition to the basic seasonal regression model, a temperature decomposition approach was applied to distinguish long-term climatic effects from short-term daily temperature variations. The decomposition model suggested that both long-term seasonal changes and short-term daily temperature fluctuations contributed independently to blood pressure variability. Previous studies have also suggested that short-term and seasonal temperature changes may have different effects on blood pressure regulation (18). One of the proposed mechanisms underlying higher blood pressure values during winter is activation of the sympathetic nervous system. Cold exposure has been shown to increase renal sympathetic activity, leading to peripheral vasoconstriction and higher blood pressure. Experimental studies suggest that this effect may persist beyond the period of cold exposure, supporting its potential role in longer-term blood pressure regulation (19). This mechanism may be particularly relevant in older individuals and patients with hypertension (20).

In our population analysis, the greatest seasonal variability between winter and summer blood pressure values was observed in men aged over 50 years. This group also had a higher prevalence of arterial hypertension, greater BMI and waist circumference, higher salt intake, and a higher prevalence of smoking, all of which may contribute to increased arterial stiffness and could partly explain the more pronounced blood pressure variability observed in this population (21). In our analysis, seasonal blood pressure variability was more pronounced in men than in women. Although seasonal fluctuations in blood pressure have been reported in both sexes, findings regarding sex differences have been inconsistent, whereas the effect of age has been more consistently observed across studies (2). In our cohort, the greater variability among men may be partly explained by the higher prevalence of hypertension, obesity, smoking, and higher sodium intake. The reasons for the more pronounced seasonal variability observed in coastal regions remain uncertain but may be related to regional climatic characteristics and behavioral adaptations to seasonal temperature changes.

Croatia is characterized by both continental and Mediterranean climate regions, each with distinct seasonal temperature patterns and lifestyle characteristics. Differences in climate and adaptation to colder weather conditions may contribute to the more pronounced blood pressure oscillations observed in coastal regions. Our findings suggest that seasonal variation should be considered when interpreting blood pressure values, particularly in individuals at increased cardiovascular risk.

Several limitations should be considered when interpreting these findings. First, the cross-sectional design precludes causal inference regarding the relationship between ambient temperature and blood pressure. Because exposure and outcome were assessed at a single time point, the observed associations may reflect reverse causation, residual confounding, or unmeasured population characteristics rather than direct physiological effects of temperature. Second, blood pressure was measured during a single study visit. Although measurements were obtained according to standardized protocols, a single office-based assessment may not adequately capture an individual's usual blood pressure level, seasonal variability, or short-term fluctuations related to physical activity, emotional stress, recent dietary intake, medication timing, or the white-coat effect. The absence of repeated measurements, home blood pressure monitoring, or ambulatory blood pressure monitoring limits assessment of within-person temporal variability and may have introduced non-differential measurement error. Third, ambient temperature exposure was estimated using meteorological data from the nearest monitoring station rather than individual-level exposure measurements. Consequently, the assigned temperature values may not accurately reflect participants' actual thermal exposure, which is influenced by time spent indoors and outdoors, housing characteristics, heating and cooling practices, occupational conditions, clothing, and personal behavioural adaptations. Such exposure misclassification may be particularly relevant in geographically heterogeneous regions and could have attenuated or distorted observed associations. Furthermore, the analysis did not incorporate other environmental factors known to influence blood pressure, including relative humidity, atmospheric pressure, wind speed, precipitation, air pollution, daylight duration, and extreme weather events, which may act as confounders or effect modifiers. Fourth, despite adjustment for several important covariates, residual confounding remains possible. Information regarding physical activity, dietary patterns beyond sodium intake, alcohol consumption, socioeconomic status, educational attainment, psychosocial stress, sleep characteristics, indoor temperature conditions, medication adherence, and seasonal changes in health-related behaviours was not comprehensively incorporated into the analytical models. These factors may vary substantially across seasons and regions and could partially explain the observed associations. Similarly, antihypertensive treatment was considered as a binary variable, but detailed information regarding medication class, dosage, treatment intensity, seasonal medication adjustments, and adherence was unavailable. Because different antihypertensive agents may interact differently with thermoregulatory and haemodynamic responses, residual treatment-related confounding cannot be excluded. Fifth, although the study used a nationally representative sample of Croatian adults, selection bias remains possible. Participants with available meteorological matching data constituted a subset of the original cohort, and excluded individuals may have differed systematically in demographic, clinical, or geographic characteristics. In addition, subgroup analyses according to sex, age, and region may have been affected by reduced statistical power and increased risk of

chance findings due to multiple comparisons. Sixth, the temperature decomposition approach provides a useful framework for distinguishing short-term and long-term temperature effects; however, the underlying assumptions of the model warrant consideration. The observed associations may not necessarily reflect independent biological mechanisms, and potential collinearity between seasonal patterns, behavioural adaptations, and climatic variables cannot be completely excluded. Moreover, the analysis assumed predominantly linear relationships between temperature and blood pressure, whereas previous studies have suggested potential non-linear or threshold effects, particularly at extreme temperatures. The lack of formal assessment of non-linearity may therefore underestimate the complexity of temperature–blood pressure relationships. Finally, the study was conducted within a single country characterized by specific continental and Mediterranean climatic zones, healthcare practices, lifestyle patterns, and sociodemographic characteristics. Consequently, the generalizability of these findings to populations living in different climatic, ethnic, socioeconomic, or healthcare settings may be limited. Prospective longitudinal studies incorporating repeated blood pressure measurements, individual-level environmental exposure assessment, and comprehensive evaluation of behavioural and physiological mediators are required to confirm these findings and to clarify the mechanisms underlying seasonal and temperature-related blood pressure variability.

In conclusion, ambient temperature and seasonal variation were significantly associated with blood pressure values in the Croatian adult population. Blood pressure values were highest during winter and lowest during summer, with the greatest variability observed among older men and participants living in coastal regions. These findings highlight the importance of considering seasonal and environmental factors when interpreting blood pressure values.

Tables and Figures

Table 1. Baseline characteristics of the study participants

Variable	Total	Men	Women	p- value
Number of participants (n)	1645	610	1035	
Age (years)	59.0 [20.0]	60.0 [19.2]	59.0 [20.0]	0.0761
Body Mass Index (kg/m^2)	28.3 [6.7]	28.9 [5.5]	27.8 [7.3]	<0.0001
Waist circumference (cm)	98.0 [20.0]	104.0 [16.0]	94.0 [21.0]	<0.0001
Hypertension	Yes: 612 (37.2%) No: 1033 (62.8%)	Yes: 279 (45.7%) No: 331 (54.3%)	Yes: 333 (32.2%) No: 702 (67.8%)	<0.0001
Dyslipidemia	Yes: 978 (59.5%) No: 667 (40.5%)	Yes: 359 (58.9%) No: 251 (41.1%)	Yes: 619 (59.8%) No: 416 (40.2%)	0.7423
Diabetes mellitus	Yes: 228 (13.9%) No: 1417 (86.1%)	Yes: 114 (18.7%) No: 496 (81.3%)	Yes: 114 (11.0%) No: 921 (89.0%)	<0.0001
Antihypertensive drugs	Yes: 646 (39.3%) No: 999 (60.7%)	Yes: 266 (43.6%) No: 344 (56.4%)	Yes: 380 (36.7%) No: 655 (63.3%)	0.0067
Smoking status	1: 844 (54.2%) 2: 333 (21.4%) 3: 380 (24.4%)	1: 265 (45.8%) 2: 177 (30.6%) 3: 137 (23.7%)	1: 579 (59.2%) 2: 156 (16.0%) 3: 243 (24.8%)	<0.0001
Sodium intake (g/day)	8.3 [5.9]	10.2 [7.1]	7.6 [5.0]	<0.0001

Data are presented as median [IQR] or n (%); smoking status: 1 = never smoker, 2 = former smoker, 3 = current smoker

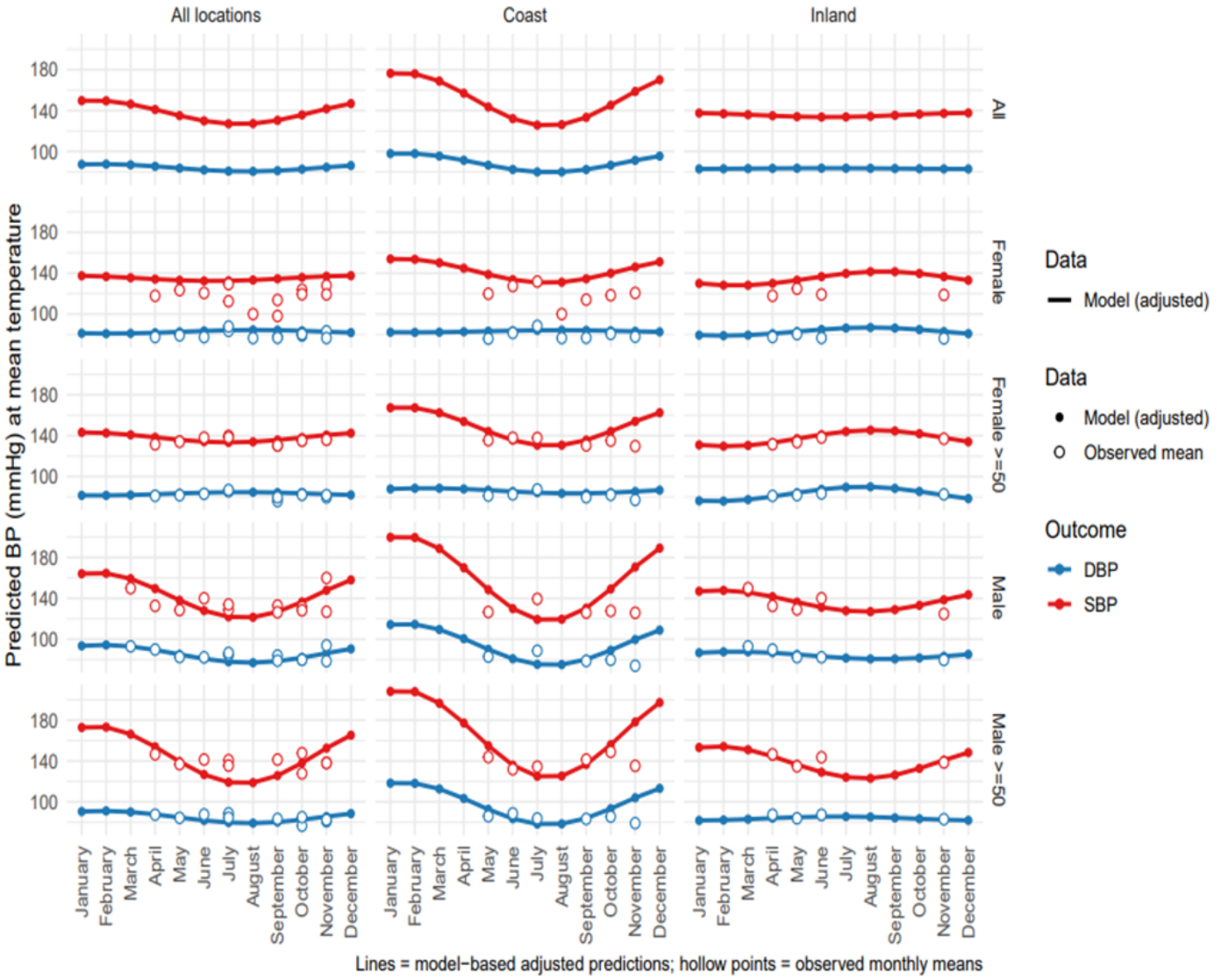

Figure 1. Seasonal variation in systolic and diastolic blood pressure according to gender, age group, and geographic region

Table 2. Systolic blood pressure values by month according to gender and geographic region

Month	Male (N)	Systolic blood pressure	Female (N)	Systolic blood pressure	Coast (N)	Systolic blood pressure	Inland (N)	Systolic blood pressure
March	1	150.0	0		0		1	150.0
April	32	141.4 ± 18.9	70	125.3 ± 13.2	0		102	130.4 ± 16.9
May	203	134.4 ± 17.6	326	130.9 ± 18.1	120	133.2 ± 19.9	409	131.9 ± 17.4
June	34	141.3 ± 16.8	70	133.9 ± 17.6	30	135.8 ± 15.4	74	136.5 ± 18.6
July	48	135.4 ± 16.3	68	137.4 ± 19.6	88	136.0 ± 18.4	0	
August	0		1	100.0	1	100.0	0	
September	54	135.5 ± 17.2	101	122.6 ± 18.0	151	127.2 ± 18.8	0	
October	69	141.8 ± 21.4	143	131.0 ± 18.9	191	135.0 ± 20.8	0	
November	169	135.4 ± 16.0	256	131.9 ± 19.3	64	129.7 ± 13.9	351	133.7 ± 18.7

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References

1. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in blood pressure from 1975 to 2015: a pooled analysis of 1479 population-based measurement studies with 19.1 million participants. Lancet. 2017;389(10064):37-55.
2. Stergiou GS, Palatini P, Modesti PA, Asayama K, Asmar R, Bilo G, et al. Seasonal variation in blood pressure: evidence, consensus and recommendations for clinical practice. Consensus statement by the European Society of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability. J Hypertens. 2020;38(7):1235-43.
3. Stevens SL, Wood S, Koshiaris C, Law K, Glasziou P, Stevens RJ, et al. Blood pressure variability and cardiovascular disease: systematic review and meta-analysis. BMJ. 2016;354:i4098.
4. Stergiou GS, Palatini P, Modesti PA, Asayama K, Asmar R, Bilo G, et al. Seasonal variation in blood pressure: evidence, consensus and recommendations for clinical practice. Consensus statement by the European Society of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability. J Hypertens. 2020;38(7):1235-1243.
5. Li Y, Wu J, Xu Y, Dong J, Xing B, Wang Y, et al. Cold exposure and the cardiovascular system: from physiological adaptation to pathological risk. Front Physiol. 2026;16:1740919.
6. Miró Ò, Benito-Lozano M, López-Ayala P, Rodríguez S, Llorens P, Yufera-Sánchez A, et al. Influence of meteorological temperature and pressure on the severity of heart failure decompensations. J Gen Intern Med. 2023;38(3):600-609.
7. Cramer MN, Gagnon D, Laitano O, Crandall CG. Human temperature regulation under heat stress in health, disease, and injury. Physiol Rev. 2022;102(4):1907-1989.
8. Nilles EK, Champon X, Mulder H, Shaw KM, Smith M, Lampron ZM, et al. Seasonal variation in blood pressure control across US health systems. J Hypertens. 2023;41(5):751-758.

9. Barbosa ECD, Farina GS, Basso CS, Camafort M, Coca A, Nadruz W. Seasonal variation in blood pressure: what is still missing? Front Cardiovasc Med. 2023;10:1233325.
10. Wang Q, Li C, Guo Y, Barnett AG, Tong S, Phung D, et al. Environmental ambient temperature and blood pressure in adults: a systematic review and meta-analysis. Sci Total Environ. 2017;575:276-286.
11. Lewington S, Li L, Sherliker P, Guo Y, Millwood I, Bian Z, et al. Seasonal variation in blood pressure and its relationship with outdoor temperature in 10 diverse regions of China: the China Kadoorie Biobank. J Hypertens. 2012;30(7):1383-1391.
12. Iwahori T, Miura K, Obayashi K, Ohkubo T, Nakajima H, Shiga T, et al. Seasonal variation in home blood pressure: findings from nationwide web-based monitoring in Japan. BMJ Open. 2018;8:e017351.
13. Hanazawa T, Asayama K, Watabe D, Hosaka M, Satoh M, Yasui D, et al. Seasonal variation in self-measured home blood pressure among patients on antihypertensive medications: HOMED-BP study. Hypertens Res. 2017;40(3):284-290.
14. Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. KDIGO 2024 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease. Kidney Int. 2024;105(4S):S117-S314.
15. Mancia G, Kreutz R, Brunström M, Burnier M, Grassi G, Januszewicz A, et al. 2023 ESH Guidelines for the management of arterial hypertension. J Hypertens. 2023;41(12):1874-2071.
16. Narita K, Kario K. Seasonal variation in blood pressure and its impact on target organ damage and cardiovascular disease incidence. Hypertens Res. 2023;46(7):1710-1.
17. Goyal A, Aslam N, Kaur S, Soni RK, Midha V, Chaudhary A, et al. Factors affecting seasonal changes in blood pressure in North India: a population based four-seasons study. Indian Heart J. 2018;70(3):360-7.
18. Woeckel M, Schneider A, Cyrys J, Wolf K, Meisinger C, Heier M, et al. Ambient air temperature and temperature variability affecting blood pressure-a repeated-measures study in Augsburg, Germany. Environ Res Health. 2023;1(3):035001.
19. Yoshimoto M, Yagi K, Ikegame S, Miki K. Progressive increase in renal sympathetic nerve activity induced by cold exposure. Hypertension. 2025;82(4):615-23.
20. Narita K, Hoshide S, Fujiwara T, Kanegae H, Kario K. Seasonal variation of home blood pressure and its association with target organ damage: the J-HOP Study (Japan Morning Surge-Home Blood Pressure). Am J Hypertens. 2020;33(7):620-8.
21. Herzog MJ, Müller P, Lechner K, Stiebler M, Arndt P, Kunz M, et al. Arterial stiffness and vascular aging: mechanisms, prevention, and therapy. Signal Transduct Target Ther. 2025;10(1):282.