Relationship Between Blood Pressure and Outdoor Temperature in a Large Sample of Elderly Individuals

The Three-City Study

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Background: Seasonal variations of blood pressure–related diseases have been described in several populations. However, few studies have examined the seasonal variations of blood pressure in the elderly, a segment of the population particularly exposed to vascular diseases. The association of blood pressure with season and outdoor temperature was examined in 8801 subjects 65 years or older from the Three-City study, a population-based longitudinal study.

Methods: Blood pressure was measured at baseline and 2-year follow-up examinations. Daily outdoor temperature measured at 11 AM was provided by the local meteorological offices.

Results: Both systolic and diastolic blood pressure values differed significantly across the 4 seasons and across the quintiles of the distribution of outdoor temperature. Systolic blood pressure decreased with increasing temperature, with an 8.0–mm Hg decrease between the lowest (≤7.9°C) and the highest (≥21.2°C) temperature quintile. Intraindividual differences in blood pressure between follow-up and baseline examinations were strongly correlated with differences in outdoor temperature. The higher the temperature at follow-up compared with baseline, the greater the decrease in blood pressure. Longitudinal changes in blood pressure according to difference in outdoor temperature were larger in subjects 80 years or older than in younger participants.

Conclusions: Outdoor temperature and blood pressure are strongly correlated in the elderly, especially in those 80 years or older. During periods of extreme temperatures, a careful monitoring of blood pressure and antihypertensive treatment could contribute to reducing the consequences of blood pressure variations in the elderly.

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EASONAL VARIATION IN BLOOD
pressure was described more
than 40 years ago by Rose. Since then, several studies have shown that arterial blood pressure tends to increase with decreasing outdoor temperature. This inverse correlation has been described in both normotensive and hypertensive populations, as well as in patients with end-stage renal disease. Studies suggested that temperature-associated variations of systolic blood pressure (SBP) and diastolic blood pressure (DBP) increase with age in adult populations. However, these studies had small sample sizes, in particular those investigating within-subject correlations, and most were conducted in highly selected participants. Only 1 large study (N=17 000), the Medical Research Council (MRC) treatment trial for mild hypertension, has examined the relationship between temperature-related variation in blood pressure and age, but no participant older than 64 years was included in that study.

Elderly persons may be particularly susceptible to temperature-related variations in blood pressure. The baroreflex, which is one of the mechanisms of blood pressure regulation, is modified in elderly subjects, and it has been hypothesized that disorders of baroreflex control and enhanced vasoreactivity could contribute to the aging-associated increase in cardiovascular morbidity. To our knowledge, no investigation of seasonal variations of blood pressure has been carried out to date within an elderly general population sample.

The Three-City Study (3C Study) is a large, population-based longitudinal study aiming to investigate the relationship between dementia and vascular disease. This study allowed us to examine the between- and within-individual relationships between arterial blood pressure...
and outdoor temperature in 8801 persons 65 years or older.

**METHODS**

The 3C Study is a population-based prospective study of the relationship between vascular factors and dementia. Participants were recruited in 3 French cities: Bordeaux (south-west), Dijon (central east), and Montpellier (southeast). The study population was randomly selected from the electoral rolls of each city. To be eligible for the study, subjects had to be 65 years or older and noninstitutionalized. Forty percent (n=9686) of the subjects meeting these criteria agreed to participate. Following recruitment, 392 subjects refused to be examined. Thus, the 3C Study population was finally constituted of 9294 subjects. Recruitment started progressively: 147 subjects were examined quarterly. The study protocol was approved by the ethical committee of the University Hospital of Kremlin-Bicêtre, and all participants signed informed consent forms.

At baseline and follow-up examinations, face-to-face interviews and measurements were performed at home or at the study center by trained nurses or psychologists.

**BLOOD PRESSURE MEASUREMENT**

Blood pressure was measured twice during the interview by trained lay interviewers, after the subject had at least 5 minutes of rest in a seated position, with an appropriately sized cuff placed on the right arm, using a validated digital electronic tensiometer (OMRON M4; OMRON Corp, Kyoto, Japan). The mean of both measures was used in the analyses.

**MEDICATION USE**

All drugs (prescription and over-the-counter drugs) used during the preceding month were recorded. To reduce underreporting, participants were asked to show all their medical prescriptions and drug packages. The trade names of all drugs were recorded. Drug names were coded according to the Anatomic Therapeutic Chemical classification recommended by the World Health Organization. Use of antihypertensive drugs was classified according to the number and the type of antihypertensive medications taken (diuretics, β-blockers, angiotensin-converting enzyme inhibitors, and others). Total number of medications and use of psychotropic drugs were also taken into account in this study.

**DEFINITION OF HIGH BLOOD PRESSURE AND HYPERTENSION**

High blood pressure was defined as a mean SBP greater than or equal to 160 mm Hg or a mean DBP greater than or equal to 95 mm Hg. Participants were classified as hypertensive either if they had high blood pressure or if they were using antihypertensive medications, or both. Subjects with a mean SBP greater than or equal to 140 mm Hg or a mean DBP greater than or equal to 90 mm Hg were considered as having elevated blood pressure.

**OTHER DATA AND MEASUREMENTS**

Information on demographic and socioeconomic characteristics included sex, age, education, occupation, and income. Three age groups were defined (65-74 years, 75-79 years, and ≥80 years). Data on past and present alcohol and tobacco consumption were collected. Subjects were classified as current, former, or never drinkers/smokers. A medical interview focused on cardiovascular and cerebrovascular diseases and on vascular risk factors (hypertension, diabetes, etc). The examination also included an evaluation of depression and anxiety. Depression was assessed with the Center for Epidemiologic Study-Depression (CES-D) scale. The CES-D consists of 20 self-reported items about symptoms and feelings experienced during the 2 preceding weeks. Each item is scored from 0 to 3 according to the frequency of the symptom. High depressive symptoms were defined as CES-D scores of 17 or greater in men and 23 or greater in women. The 20-item Spielberger Inventory-Trait scale was used to measure anxiety symptoms. Body mass index (BMI) was computed from height and weight measurements (weight in kilograms divided by height in meters squared).

**METEOROLOGICAL DATA**

Data about temperature and atmospheric pressure for the period January 1999 through December 2002 were provided by the French National Meteorological Office. For the purpose of this study, we used daily outdoor temperature measured at 11 AM by the local meteorological office in Bordeaux, Dijon, and Montpellier. Daily measures of atmospheric pressure were available for the same period. The 4 seasons were defined as follows: winter from December 21 to March 20, spring from March 21 to June 20, summer from June 21 to September 20, and autumn from September 21 to December 20. Mean (SD) winter and summer temperatures (degrees Celsius) were 8.6 (4.0) and 21.2 (3.0), respectively, in Bordeaux, 4.9 (4.4) and 19.7 (3.2) in Dijon, and 8.9 (4.1) and 24.5 (2.7) in Montpellier.

**STATISTICAL ANALYSIS**

Variance analysis was used to compare the distribution of the baseline measures of SBP and DBP across the 4 seasons. Seasonal variations in other characteristics of the study participants were also examined. These included sex, age, use of antihypertensive drugs, depression and anxiety symptoms, use of psychotropic drugs, alcohol and tobacco consumption, and BMI. Seasonal rhythm of blood pressure values was further analyzed by applying partial Fourier series to the time series data for the period January 1999 through December 2002. For this chronological analysis, we used SAS statistical software, version 9.0 (SAS Institute Inc, Cary, North Carolina). This method (spectral analysis) provides the estimated statistic of the rhythm, taking into account the overall temporal trend of the blood pressure values during the studied period. The statistical significance of the estimated rhythm was assessed by the Bartlett-Kolmogorov-Smirnov test. Variation in blood pressure across the quintiles of the overall distribution of the daily temperatures during the period January 1999 through March 2001 was also analyzed in the whole sample and in different strata based on age, sex, use of antihypertensive medication, BMI, and smoking habits. The relationship between blood pressure and atmospheric pressure data was analyzed in the same way. We then investigated the possible influence of temperature on within-subject variations in blood pressure between baseline and follow-up examinations. For each subject, we calculated first the mean temperature of the 3 days preceding his or her blood pressure measurement and then the difference between the mean temperatures at follow-up and baseline. A positive difference indicated that outdoor temperature was lower at study entry than at follow-up examination. Differences be-
RESULTS

After having excluded 493 subjects because their baseline blood pressure measurements were missing, the study sample consisted of 8801 subjects (mean [SD] age, 74.3 [5.6] years; proportion of men, 39.4%).

Table 1 shows the distribution of the main characteristics of the study sample by season at study entry (January 1999–March 2001). Both SBP and DBP values differed significantly across the 4 seasons, with a clear trend for decreased blood pressure in spring and summer compared with autumn and winter. The proportion of subjects with a high or elevated blood pressure was significantly lower during the warmest seasons, as was the proportion of subjects classified as hypertensive. Heart rate was slightly but significantly higher in autumn and winter than in the warmer seasons. Among the other characteristics of the study sample, age, number of drugs used, prevalence of high depressive symptoms, and proportion of psychotropic users showed significant seasonal variations. They were all slightly but significantly increased in participants who had been examined in spring and summer.

The figure illustrates the seasonal variations of SBP and DBP during the first wave of the study (26 months), for the whole sample and by sex. It confirms that blood pressure values decreased in spring and summer, then increased and showed a winter peak. In agreement with this crude analysis, spectral analysis detected a significant 13-month rhythm in blood pressure values during the period January 1999 through December 2002, which covered the first 2 waves of the study (recruitment and first follow-up examination) (Bartlett-Kolmogorov-Smirnov test = 0.42, \( P < .001 \)).

Table 2 describes variation in SBP according to the quintiles of the distribution of outdoor temperature. The SBP decreased strongly with increasing temperatures, in the whole sample and in all strata. In the whole sample, the proportion of subjects who showed significant seasonal variations. They were all slightly but significantly increased in participants who had been examined in spring and summer.

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there was an 8.0–mm Hg decrease in SBP between the lowest (<7.9°C) and the highest (≥21.2°C) temperature quintile. Linear trends were all statistically significant. Similarly, DBP decreased regularly with increasing temperature (data not shown). In the whole sample, DBP decreased from 82.8 mm Hg in the first quintile of the temperature distribution to 79.1 (12.1) mm Hg for DBP. As shown in Table 3, there was a sharp association between the magnitude of the decrease of the intraindividual SBP and DBP values and the difference between the outdoor temperatures at baseline and follow-up. The higher the temperature at follow-up compared with baseline, the larger the SBP and DBP decrease. This trend was found in both sexes, in all age groups, and in all 3 centers. Changes in blood pressure according to differences in outdoor temperature were larger in subjects 80 years or older (n=1142) than in younger participants. For a 15°C decrease in outdoor temperature, SBP increased 0.8 mm Hg in subjects aged 65 to 74 years compared with 5.1 mm Hg in the oldest group (≥80 years).

Table 2. Mean (SD) Systolic Blood Pressure by Quintile of Outdoor Temperature in the Whole Study Population and in Different Strata

<table>
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<th>Category</th>
<th>N</th>
<th>1st (SD)</th>
<th>2nd (SD)</th>
<th>3rd (SD)</th>
<th>4th (SD)</th>
<th>5th (SD)</th>
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<td>150.1 (22.6)</td>
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<td>154.3 (22.6)</td>
<td>154.8 (21.9)</td>
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<td>65-74</td>
<td>4884</td>
<td>147.5 (21.7)</td>
<td>147.1 (22.3)</td>
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<td>148.9 (21.9)</td>
<td>149.8 (22.1)</td>
<td>142.3 (22.5)</td>
<td>137.3 (18.9)</td>
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<td>1979</td>
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<td>147.2 (21.4)</td>
<td>146.0 (23.5)</td>
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<td>137.6 (20.5)</td>
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<td>Dijon</td>
<td>4773</td>
<td>151.0 (23.3)</td>
<td>150.7 (23.6)</td>
<td>147.4 (22.4)</td>
<td>146.4 (24.5)</td>
<td>143.0 (23.0)</td>
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<td>Montpellier</td>
<td>2049</td>
<td>147.6 (20.2)</td>
<td>145.9 (19.8)</td>
<td>143.3 (19.0)</td>
<td>143.8 (18.0)</td>
<td>143.2 (18.4)</td>
</tr>
</tbody>
</table>

Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

a Systolic Blood Pressure by Quintile of Outdoor Temperature, mm Hg.

b P values for linear trend, adjusted for center, age, sex, depression score, number of drugs used, and psychotropic drug use, were <.001 for all comparisons.

c Category totals may vary because data were missing for some subjects.
80 years or older. Similarly, change in DBP in relation to differences between follow-up and baseline temperatures were greater in older than in younger participants.

Similar analyses were performed for atmospheric pressure time series. They did not show any relationship between atmospheric pressure and blood pressure.

COMMENT

In this large, population-based study of elderly individuals, we observed a strong relationship between blood pressure and season. During winter, mean SBP was 5.0 mm Hg higher than in summer. Accordingly, prevalence of high blood pressure (SBP ≥ 160 mm Hg or DBP ≥ 95 mm Hg) decreased from 33.4% to 23.8% between winter and summer. The 3C Study also provided us with the opportunity to examine the relationship between external temperature and blood pressure measures. It showed that blood pressure was strongly influenced by outdoor temperature in the elderly. Its consequences were not negligible: the mean SBP varied from 150.1 mm Hg to 142.1 mm Hg between the lowest and highest quintiles of external temperature. Moreover, difference in individual blood pressure measures between baseline and 2-year follow-up visits was also strongly correlated with difference in outdoor temperature. Our data suggested, furthermore, that the temperature-related variations in both SBP and DBP could be increased in very old persons.

The seasonal variations of blood pressure as well as the relationship between blood pressure and external temperature have been studied for many years. However, most studies have been based on small or medium-sized samples of selected individuals, with repeated measurements of blood pressure. Studies have also investigated which factors could explain or modify the relationship between blood pressure and season or temperature. In about 100 normotensive men aged 28 to 63 years, seasonal variations in blood pressure were inversely associated with BMI and were greater among smokers than nonsmokers. The inverse association between seasonal variations in blood pressure and BMI was also found in the 17 000 men and women participating in the MRC trial for mild hypertension. In the MRC trial, the increase in both SBP and DBP in the cold seasons was greater in older (55-64 years) than in younger (35-54 years) subjects. Few studies have been performed in elderly individuals. One study performed in individuals aged 65 to 74 years was based on only 96 subjects recruited in 1 general practice. In that study, blood pressure was correlated with ambient temperature, but external temperature was not analyzed.

Some biases have to be considered in our study. The sample of elderly individuals was not representative of the general population, but prevalence of high blood pressure, use of antihypertensive or lipid-lowering drugs, obesity, and other chronic conditions was consistent with that in other studies. Overall, there were few changes in the characteristics of our study population between baseline and follow-up visits. A possible confounding effect of alcohol consumption in winter or of increased physical activity in summer resulting in lower BMI could be excluded in our study because we did not find any seasonal variation in alcohol consumption or BMI. Modification of diet between seasons and its potential effect on blood pressure could not be tested in the present study because there was no detailed diet questionnaire in the 3C Study. A high level of physical activity can influence blood pressure independently of its effect on BMI, but it is an unlikely explanation of the association between temperature and blood pressure in persons 80 years or older. Mechanisms that could explain the association between blood pressure and temperature remain undetermined. Activation of the sympathetic nervous system and secretion of catecholamine are increased in response to cold temperatures. This could result in an increase in blood pressure through increased heart rate and peripheral vascular resistance. In the present study, the significant seasonal variations in heart rate were consistent with this hypothesis but were small (71.7 beats/min in winter vs 70.8 beats/min in summer). In relation to this hypothesis, one would expect an influence of hypertension treatment, especially with a β-blocker, on the relationship between blood pressure and temperature. However, neither the MRC trial nor our study found any impact of hypertension treatment on the variations in blood pressure with temperature. Endothelium-dependent mechanisms could also be involved in the relationship between temperature and vasodilation, as suggested by a recent study.

Whatever the mechanisms involved in this association, they must have a long-lasting effect on blood pressure. In our study, as in other studies, blood pressure measurements were made in rooms where temperature in winter is around 20°C. In winter, participants who were examined at home in the morning had usually spent more than 12 hours in warm rooms. This suggests that indoor temperature in its usual range has limited influence on blood pressure. A few studies have examined the association of indoor temperature with blood pressure but showed inconsistent findings.

Although our study does not demonstrate a causal link between blood pressure and external temperature, the observed relationship nevertheless has potentially important consequences for blood pressure management in the elderly. It may be hypothesized that a higher blood pressure in winter could partly explain the well-established sea-
seasonal variations in mortality and incidence of vascular diseases, including stroke,\footnote{21} and, in particular, cerebral hemorrhage,\footnote{22} abdominal aortic aneurysm rupture,\footnote{23} aortic dissection,\footnote{24} and subarachnoid hemorrhage.\footnote{25,26} Our study showed that variations in blood pressure with temperature were greater in older persons (80 years or older) than in younger elderly. Because the risk of stroke or aneurysmal rupture is highest in the elderly, improved protection against these diseases by close monitoring of blood pressure and antihypertensive medication when outdoor temperature is very low could be considered. Conversely, low blood pressure is also a known risk factor for morbidity and mortality in elderly persons.\footnote{27,28} In August 2003, there was an unprecedented heat wave in France that resulted in about 15,000 deaths, mainly in the elderly. This heat wave affected the blood pressure of the 3C Study participants who had their second follow-up examination during this period. The seasonal fall of the blood pressure values was sharper in August 2003 (mean SBP, 132 mm Hg) than, for example, in August 2004 (138 mm Hg). Because decreased blood pressure may be a risk factor for increased mortality in persons with environmental hyperthermia,\footnote{29} monitoring of blood pressure in the elderly could be an important issue under these extreme conditions.

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