Original Article

Seasonal Influence on Blood Pressure in Elderly Normotensive Subjects

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The aim of this study was to examine whether or not fluctuations in blood pressure (BP) differ by season. Subjects were 45 elderly individuals (20 men and 25 women; mean age, 66.5±4.9 [SD] years). Each subject's BP was recorded with an ambulatory BP monitoring device for 24 h during each of the four seasons. Subjects also wore a portable weather meter to obtain ambient temperature, relative humidity, and barometric pressure simultaneously with BP. The relationships between meteorologic values and BP were investigated at various parts of the day. Seasonal differences in BP fluctuation around wake-up-time were analyzed by means of the Tukey's test. The difference between the pre–wake-up-time systolic BP and the wake-up-time systolic BP was significantly greater in winter than in summer (8.7 mmHg greater, $p<0.001$). The difference between pre–wake-up-time and wake-up-time systolic BP was significantly greater in autumn than in spring (9.4 mmHg greater, $p<0.001$) or summer (13.1 mmHg greater, $p<0.001$). The difference between pre–wake-up-time heart rate and wake-up-time heart rate did not differ statistically between seasons. In conclusion, the present study showed that the difference between pre–wake-up-time systolic BP and wake-up-time systolic BP was greatest in the colder seasons, *i.e.*, autumn and winter. There appears to be a large fluctuation in wake-up-time in the colder seasons. Low ambient temperature likely induces this large fluctuation. (*Hypertens Res* 2008; 31: 569–574)

Key Words: **ambulatory blood pressure, heart rate, seasonal variation, meteorologic factors**

Introduction

Blood pressure (BP) is reported to fluctuate in response to environmental factors such as season and weather (*1–4*). Many studies have shown seasonal variation in BP, particularly an increase in BP during the cold seasons (*5–7*). Because seasonal variation in BP is thought to be related to seasonal variation in the occurrence of stroke (*8*, *9*) and cardiovascular disease (*10*, *11*), assessing the influence of seasonal and meteorologic conditions on BP is clinically relevant for controlling BP.

Ambulatory BP monitoring (ABPM) has been used to evaluate BP over a 24-h period (*12*) in elderly hypertensives. This method can also be used to assess daily fluctuations in BP (*13*).

We investigated the relationships between BP and meteorologic factors such as temperature, humidity, and barometric pressure in elderly normotensive subjects using an ABPM device and a portable weather meter. We also quantitatively assessed seasonal differences in BP according to various periods of the day, such as daytime, nighttime, and wake-up-time.

Methods

Subjects

Elderly residents of Tokyo, Japan, were recruited for the

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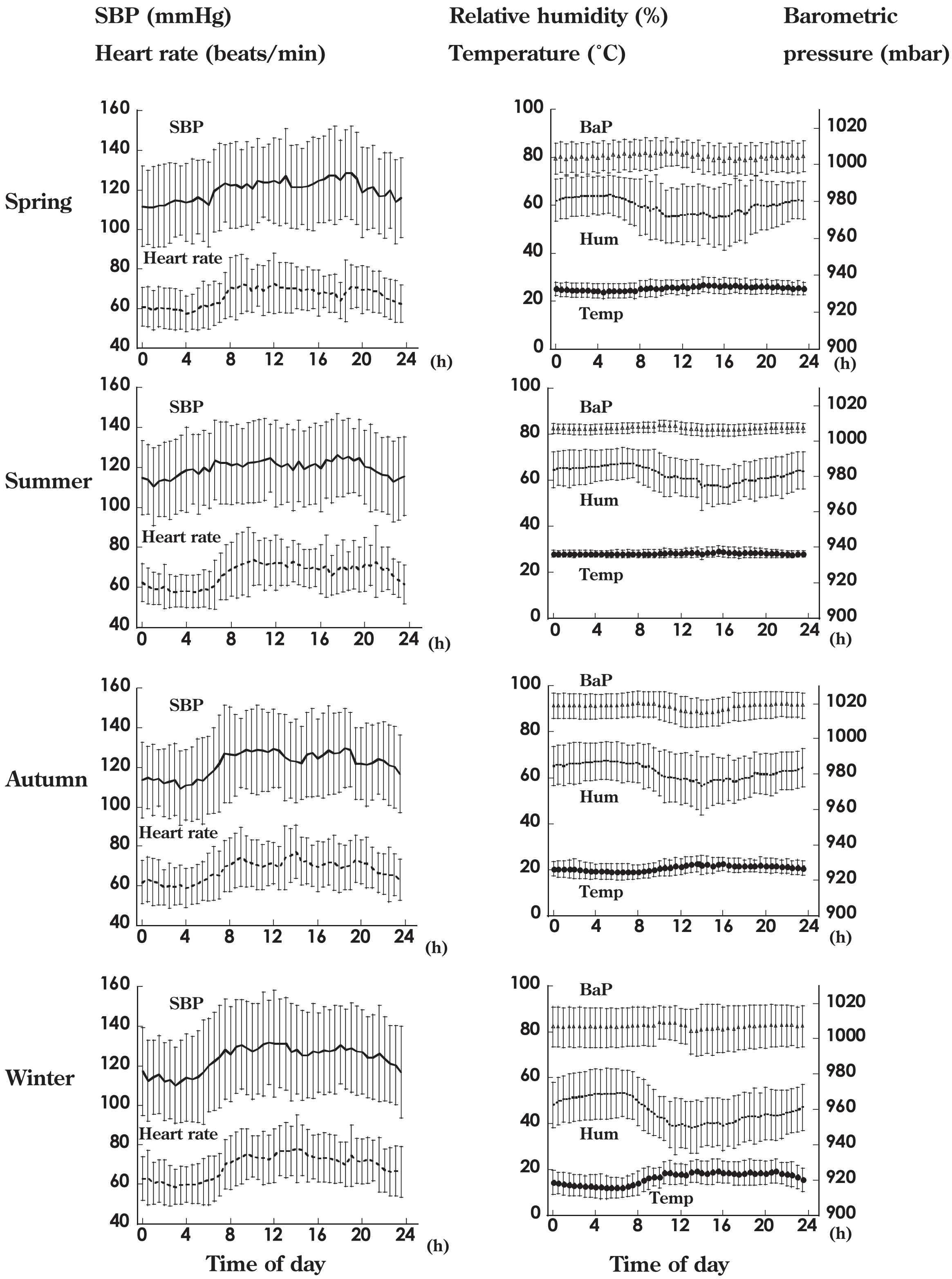

Fig. 1. *Mean SBP and heart rate per time of day measured every 30 min for each season (left) and mean meteorologic values, i.e., ambient temperature (Temp: °C), relative humidity (Hum: %) and barometric pressure (BaP: mbar), corresponding to the time points at which BP was measured. Bar: SD.*

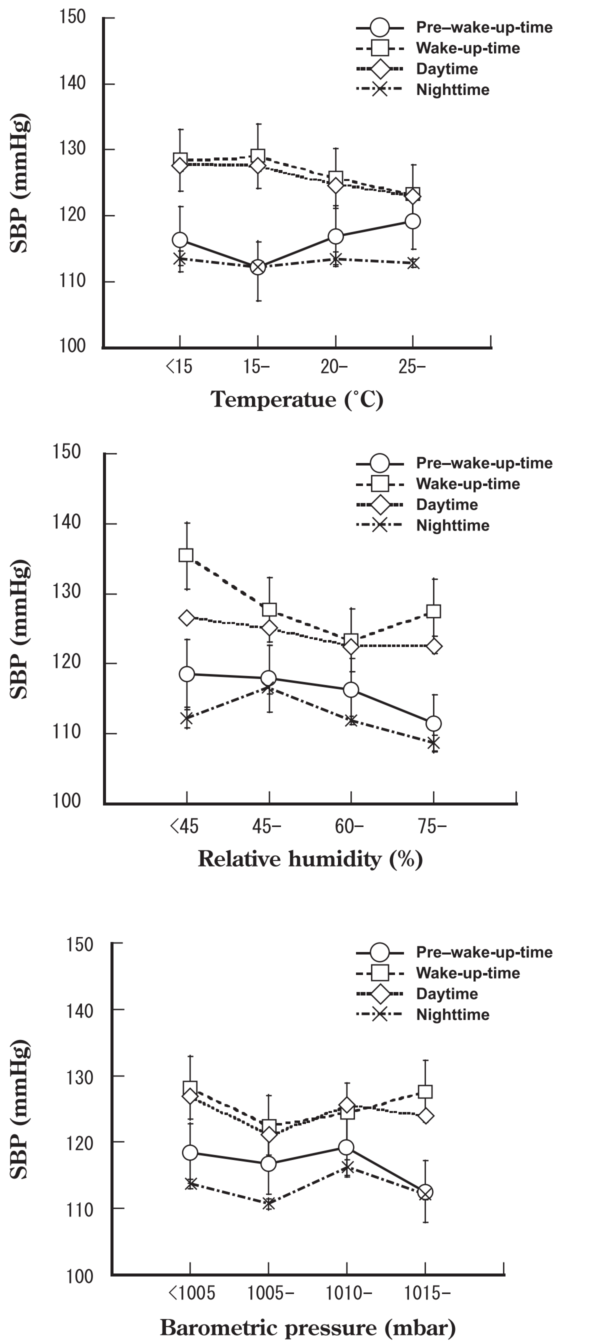

Fig. 2. *Mean SBP for the four time periods: wake-up-time, daytime, nighttime, and pre–wake-up-time according to ambient temperature at intervals of 5°C, relative humidity at intervals of 15%, and barometric pressure at intervals of 5 mbar. Bar: SEM.*

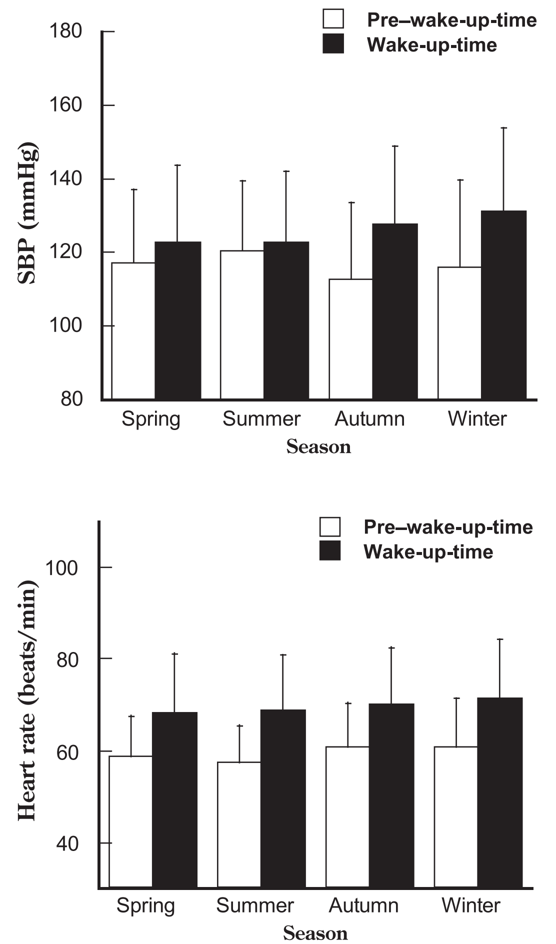

Fig. 3. *Differences in SBP and heart rate between pre–wake-up-time and wake-up-time per season. Bar: SD.*

study. The eligibility criteria were 1) age 50 years or greater, 2) no history of antihypertensive medication, and 3) independence in activities of daily living. A total of 86 volunteers met the criteria and were enrolled in the study. Of these, three were found to have hypertension requiring treatment; they were eventually excluded from the study and advised to consult a doctor.

Examinations were conducted four times (spring, summer, autumn and winter) in 1 year, and some subjects missed an examination. Of the original 86 enrollees, 45 (20 men and 25 women) completed all four examinations. The present study included only these 45 subjects. The mean age of the male subjects was 63.8 years (SD, 4.4) and that of the female subjects was 68.6 years (SD, 4.2).

All subjects were given detailed information about the investigation, and all provided written informed consent. The study protocol was approved by the ethics committee of Yokohama City University School of Medicine.

Twenty-Four-Hour ABPM

The examinations were conducted from April 2004 through March 2005. Examinations for spring, summer, autumn, and winter were conducted in April–June, July–August, October–November, and January–March, respectively. For all exami-

Table 1. Results of Tukey's Test for Seasonal Differences in SBP and Heart Rate between Pre–Wake-Up-Time and Wake-Up-Time

Variables		Mean difference	95% confidence interval		SEM	*p* value
			Lower	Upper		
*Δ*SBP						
Winter	Spring	5.1	−0.5	10.7	2.1	0.09
	Summer	8.7	3.2	14.3	2.1	0.00
	Autumn	−4.3	−9.9	1.2	2.1	0.19
Autumn	Spring	9.4	3.8	15.0	2.1	0.00
	Summer	13.1	7.5	18.6	2.1	0.00
Summer	Spring	−3.6	−9.2	1.9	2.1	0.33
*Δ*Heart rate						
Winter	Spring	1.4	−3.5	6.2	1.9	0.89
	Summer	1.4	−3.5	6.2	1.9	0.89
	Autumn	1.6	−3.3	6.5	1.9	0.83
Autumn	Spring	−0.3	−5.1	4.6	1.9	1.00
	Summer	−0.3	−5.1	4.6	1.9	1.00
Summer	Spring	0.0	−4.9	4.9	1.9	1.00

SBP, systolic blood pressure.

nations, each subject wore a compact ABPM (ES-H531; Terumo Co., Tokyo, Japan) for 24 h. BP and heart rate were measured and recorded by the device every 30 min. Subjects were asked to go about their usual daily activities and to note the times that they woke up and went to bed.

Weather Data

For 24 h, each subject wore a portable weather meter (Kestrel 2000; Nielsen-Kellerman, Boothwyn, USA) that measured and recorded ambient temperature (°C), relative humidity (%), and barometric pressure (mbar). These meteorologic values were obtained every 30 min simultaneously with the BP values.

Data Analysis

Mean systolic BP (SBP)±SD and mean heart rate±SD of all subjects were calculated for each time point that BP was measured. The relationships between SBP and ambient temperature, relative humidity, and barometric pressure were evaluated for four time periods: 1) pre–wake-up-time, *i.e.*, the 2-h period before awakening; 2) wake-up-time, *i.e.*, the first 2 h after awakening; 3) daytime, *i.e.*, the period when the subject was awake, excluding wake-up-time; and 4) nighttime, *i.e.*, the period when the subject slept, excluding the pre–wake-up-time. Ambient temperature, relative humidity, and barometric pressure were divided into incremental ranges of 5°C, 15%, and 5 mbar, respectively. Differences between pre–wake-up-time and wake-up-time SBP and heart rate were tested for statistical significance by the Tukey's test.

p values of less than 0.05 were taken as statistically significant. Statistical analyses were performed with SPSS Regression Models (SPSS Japan, Tokyo, Japan).

Results

Mean SBP and heart rate at each time point are shown with corresponding meteorologic data in Fig. 1. Marked circadian fluctuation in SBP was seen in autumn and winter. A rapid increase in SBP was observed in the early morning in autumn and winter.

Figure 2 shows the relationships between SBP and meteorologic values by time period: wake-up-time, daytime, nighttime, and pre–wake-up-time. SBP during pre–wake-up-time tended to increase as temperature increased. Thus, the difference in SBP between pre–wake-up-time and wake-up-time became small when the temperature was high. A negative association was found between relative humidity and SBP for each time period.

Differences between pre–wake-up-time and wake-up-time SBP and heart rate are shown by season in Fig. 3. SBP rose upon awakening in all four seasons. The difference in SBP was larger in autumn and winter than in spring and summer. Heart rate also increased upon awakening in all four seasons.

Results of the Tukey's test are shown in Table 1. Differences between the pre–wake-up-time and wake-up-time SBP were significantly greater in winter than in summer (8.7 mmHg greater on average). The difference between pre–wake-up-time and wake-up-time SBP was also significantly greater in autumn than in spring (9.4 mmHg greater on average) or in summer (13.1 mmHg greater on average). The difference in heart rate between pre–wake-up-time and wake-up-time did not differ statistically from season to season.

Discussion

The results of this study indicate that there are seasonal variations in BP and that weather conditions affect those values. Dry and cool weather conditions are likely to increase BP, especially in the wake-up-time and daytime. Seasonal variation in BP has been reported by many researchers (*1–7*). Brennan *et al*. reported that in the UK, BP tended to be higher in winter than in summer and that this tendency was greater in older persons than in younger persons (*14*). Sega *et al*. investigated seasonal variations in ambulatory BP, home BP, and clinic BP in a large-scale study in Italy and reported that 24-h average BP, taken from both home and clinic measurements, was higher in winter than in summer (*15*).

The most plausible explanation for the seasonal variations in BP is ambient temperature. It has been reported that BP is negatively associated with ambient temperature. Woodhouse *et al*. estimated that, with a 1°C decrease in living-room temperature, SBP increased by 1.3 mmHg and diastolic BP increased by 0.6 mmHg (*16*). Kristal-Boneh *et al*. also reported, from a study of 24-h ambulatory BP, that SBP and diastolic BP rose 1.14 mmHg and 0.58 mmHg, respectively, with a 1°C decrease in ambient temperature (*17*). Consistent with those results is our finding that cold temperature increases BP during wake-up-time and daytime.

BP has a circadian pattern, characterized by a peak in the morning and another in the evening (*18*, *19*). A rapid increase in BP in the morning, referred to as a morning surge, is thought to be related to cardiovascular disease and cerebrovascular disease (*20–25*). We observed a difference between pre–wake-up-time SBP and wake-up-time SBP, and the morning surge was greater in the cold seasons than in the warm seasons. This is likely to be related to the high frequency of cardiovascular and cerebrovascular events in the winter (*26–33*). Goodwin *et al*. reported significantly higher morning BP in elderly men in winter than in summer (*34*). They suggested that the elevation in BP is related to increased activity as well as to ambient temperature. However, in our study, the rise in heart rate, which is thought to be influenced by activity, did not change remarkably between seasons, as did the rise in SBP (Fig. 3, Table 1). Jehn *et al*. reported that SBP variability increased as temperature decreased and that nighttime BP increased with increasing temperature (*35*). This phenomenon was also observed in our study, *i.e.*, BP rose during pre–wake-up-time when temperature was high. This made the difference between pre–wake-up-time and wake-up-time SBP small.

There are several limitations to our study. First, we included only elderly persons because the elderly are considered to be sensitive to meteorologic conditions; seasonal variation in BP in younger persons is outside the scope of the study. Second, differences in meteorologic conditions between spring and summer and between autumn and winter were small because our examination for each season spanned 2 to 4 months; this probably resulted in similar circadian SBP patterns between spring and summer and between autumn and winter.

In conclusion, the present study showed that the difference from pre–wake-up-time SBP and wake-up-time SBP was greatest in the colder seasons, *i.e.*, autumn and winter. The BP of elderly persons appears to change markedly around wake-up-time in he colder seasons. It is likely that low ambient temperature induces this large change.

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