Relationships of heart rate and heart rate variability with conventional and ambulatory blood pressure in the population
Robert H. Fagard, Karel Pardaens and Jan A. Staessen

Background Most studies on relationships between blood pressure and autonomic nervous function, assessed by power spectral analysis of heart rate variability, have used conventional or clinic blood pressure measurements in selected subjects, which may have influenced the results.

Objective We aimed to investigate, in a population-based approach, associations of heart rate and heart rate variability, assessed in basal resting conditions and in response to standing, with conventional blood pressure measured by an investigator, and with ambulatory blood pressure monitored outside the laboratory.

Methods RR interval and respiration were registered in 614 men and women, ages 25–89 years. After exclusion of subjects with myocardial infarction or diabetes and elimination of unsatisfactory recordings, 549 subjects remained for analyses at supine rest and 515 of these to assess the orthostatic responses. Hypertension was present in 39% of the subjects. The low-frequency (LF) and high-frequency (HF) components of heart rate variability were quantified by use of autoregressive modelling and expressed in absolute and normalized units.

Results At supine rest, indices of heart rate variability were not independently related to 24 h systolic blood pressure, whereas some indices showed weak associations with diastolic 24 h pressure; the relationships were in general stronger for conventional blood pressure. For example, partial correlation coefficients of the relationships of the LF:HF ratio with systolic pressure were 0.12 ($P < 0.01$) for conventional pressure and 0.02 (NS) for 24 h pressure; these coefficients amounted to 0.20 ($P < 0.001$) and 0.11 ($P < 0.01$) for the diastolic pressures. The decrease of HF power and the increase of the LF:HF ratio on standing were significantly blunted at higher blood pressure, both when measured conventionally and by ambulatory monitoring ($P < 0.001$ for the LF:HF ratio).

Conclusions Relationships between autonomic nervous function at rest, assessed by use of power spectral analysis of heart rate variability, and conventional blood pressure, can at least partly be ascribed to the influence of the measurement conditions, whereas the orthostatic autonomic responses appear to be influenced by blood pressure per se.

Introduction Measurements of plasma noradrenaline and of noradrenaline spillover, data from microneurography and responses to pharmacological blockade [1–3], suggest that the autonomic nervous system contributes to the development and maintenance of high blood pressure in human essential hypertension, or at least in subsets of patients. These investigations pointed to stimulation of the sympathetic nervous system or a decrease of parasympathetic activity, or both. Such studies have usually been performed in selected subjects, often in laboratory conditions, which may have influenced the results. Power spectral analysis (PSA) of short-term beat-to-beat heart rate variability (HRV), which is largely dependent on the functioning of the autonomic nervous system, provides an alternative and non-invasive method to assess autonomic cardiac modulation [4–6], suitable for studies in the population. Analysis of HRV in the frequency domain has identified a low-frequency component (LF) at approximately 0.1 Hz, and a high-frequency component (HF) coupled with the respiratory cycle. Previous work has shown that the former is under the influence of both the sympathetic and the parasympathetic nervous system and that the latter is influenced by the vagus only. Guzzetti et al. [7,8] were the first to apply this methodology to hyper-
tensive patients, who were found to have increased LF power and reduced HF power when investigated at supine rest. The results from subsequent studies in selected hypertensives [9–18] or in the population [19–21] have been variable, probably related to differences in the studied populations and in the divergent methodological approaches to data recording, spectral analysis and expression of the results. With regard to the response to sitting, standing or tilting, most [7,8,12,13,17,18] but not all [16,19] authors observed that the orthostatic changes of the LF and HF powers were blunted in hypertension. It should be noted, however, that all investigations in selected hypertensive patients have classified the patients on the basis of clinic blood pressure measurements and that population-based studies analysed relationships of heart rate and indices of its variability with conventional blood pressure. Blood pressure may therefore have been influenced by the measurement conditions, particularly the presence of the investigator [22], which may have led to spurious associations between autonomic functioning and blood pressure. Ambulatory blood pressure is closer to the subject’s usual or true blood pressure, but no study has looked whether the relationships between the components of HRV and blood pressure would also be present when blood pressure is measured outside the laboratory conditions.

The purpose of the present study was to analyse associations of heart rate, its overall variability and of the spectral components of HRV as indices of autonomic nervous function, measured in basal resting conditions and in response to standing, with blood pressure, both when measured by conventional methods and by use of ambulatory monitoring during 24 h. Analyses were performed in a population-based sample of men and women, aged 25 to 89 years, with consideration of demographic, anthropometric and lifestyle characteristics as covariates [23]. The spectral analysis was performed by both autoregressive modelling and fast Fourier transform, and the results are expressed in absolute and in normalized units.

**Methods**

**Study population**

The assessment of HRV was included in the second phase of a population-based study, of which the first phase was initiated in 1985 [24]. A random sample of 1419 adult subjects, living in a Flemish rural area, stratified by age and gender, and in which households constituted the sampling unit, was invited to participate in the period 1985–1989. Of the 1107 participants in the first phase, 1014 were alive and still living in the area when phase 2 was conducted (1991–1995). Of these subjects, 823 agreed to investigations at home (phase 2.1) and 614 of the latter to investigations in a specially set-up local laboratory (phase 2.2), where measurements including assessment of HRV were performed by trained technicians recruited from the same community. Subjects were asked not to smoke or drink caffeine, and to avoid heavy meals before the examination at the field centre. The study was approved by the institutional review committee and the subjects gave informed consent.

**Investigations**

In phase 2.2 of the population study, subjects filled in a questionnaire which inquired about each participant’s medical history, smoking habits, consumption of alcohol, occupational and leisure-time physical activity and intake of medication [25]. After measurements of height and weight, blood pressure was taken five times, by use of the auscultatory technique (Korotkoff phases I and V), after the subjects had been sitting for 5 min. A suitable lead was selected from the 12-lead electrocardiogram for the study of HRV and a nasal thermistor was applied to assess respiratory frequency. After the subjects had rested for 10 min in the supine position, the investigator withdrew from the room and the electrocardiographic and respiratory signals were recorded during the next 15 min. Thereafter, the registration continued for 15 min in the free standing position [26], during which the investigator was present in the background for safety reasons. All signals were sampled at 300 Hz.

**Heart rate variability**

The analysis of heart rate, its variability and of respiratory activity has been described in detail [27]. Analyses were performed on segments of preferably 512 consecutive beats, as close to the end of each 15 min recording as possible, unless only shorter periods appeared suitable for analysis; a previous study showed that the results from PSA were similar when periods of 512, 256 or 128 beats were used [28]. The mean RR interval (ms) and its total variance or power (ms²) were calculated. PSA was then performed to estimate the powers in the LF and HF ranges. Frequency was assessed as equivalent Hertz (henceforth called Hertz), defined as cycles per beat, divided by the mean length of the RR interval [29]. The LF and HF powers were expressed in both absolute units (ms²) and in normalized units (%) [30]; normalized or relative LF or HF power is the absolute power divided by the partial power, defined as the power between 0.03 and 0.50 Hz [5]. In addition, the LF:HF power content ratio was calculated [5]. PSA was performed by both autoregressive modelling (ARM), involving a decomposition algorithm, and by fast Fourier transform (FFT), as described [27]. ARM furnished both the power and the central frequency of the oscillatory components. The LF component was defined as that with central frequency around 0.1 Hz, ranging from 0.05 to 0.15 Hz, and the HF component as that at respiratory frequency,
as described in detail [27]. For FFT, the \emph{a priori} band determination was as follows: the LF component included the power from 0.05 to 0.15 Hz and the HF component the power from 0.15 to 0.50 Hz. Only the results from ARM will be presented in this report. Although results from FFT and ARM may differ for the individual subject [27], the overall conclusions on the relationships between BP and HRV were similar for the two approaches. Detailed results from FFT are available from the authors.

**Ambulatory blood pressure monitoring**

Ambulatory blood pressure monitoring was performed within 1 month of the conventional blood pressure measurements, with SpaceLabs 90202 monitors (SpaceLabs Inc., Redmond, Washington, USA) as described [24]. The recorders were programmed to obtain measurements at an interval of 20 min from 0800 until 2200 h and every 45 min from 2200 to 0800 h. Results are from unedited recordings. Intra-individual means of the ambulatory measurements were weighted by the time interval between successive readings. Daytime was defined as the interval from 0000 to 2000 h and night-time from midnight to 0600 h [31]. These definitions eliminate the transition periods in the morning and evening, during which the blood pressure changes rapidly in most people. These daytime and night-time pressures do not differ from those derived from the actual awake and asleep periods in patients with a normal pattern of daily activity [32].

**Statistical analysis**

The SAS software (SAS Institute, Inc., Cary, North Carolina, USA) was used for all statistical analyses. Values are reported as means and standard deviations (SD) or standard errors of the mean (SEM). Variables with positively skewed distribution were normalized by logarithmic transformation and are reported as means and standard deviations of the logarithmic values and geometric means. Statistical analyses were performed by use of the Student’s \( t \)-test, analysis of variance and covariance, and single and stepwise multiple regression analysis. The covariates considered for entry into the models were age; gender; body mass index; antihypertensive drug class (coded 1 when taken and 0 when not, for each class, separately); smoking (coded 1 for current smokers and 0 for non-smokers); alcohol consumption (coded 1 for drinkers and 0 for tea-totalers); physical activity during leisure time (sports and walking) and at work, expressed in energy expenditure (Cal) and the mean of five conventional blood pressure measurements 131 \( \pm \)82 \( \pm \)11 mmHg. We excluded 30 patients with previous myocardial infarction (\( n = 8 \)), diabetes (\( n = 21 \)), or both (\( n = 1 \)). For the analyses in the supine position, an additional 35 recordings had to be eliminated for the following reasons: no or too short registrations in four; arrhythmias or artefacts, or both, which could not be satisfactorily eliminated in 16, or breathing frequency below 0.15 Hz in 15 subjects. The characteristics of the 549 subjects who remained for the analysis of data in the supine position are given in Table 1, according to whether they were normotensive (\( n = 337 \)), hypertensive with conventional systolic blood pressure \( \geq \)140 mmHg or diastolic pressure \( \geq \)90 mmHg without antihypertensive therapy (\( n = 128 \)), or because they were on antihypertensive medication (\( n = 84 \)). Approximately half of the normotensives (55%) and half of the hypertensives (48%) were

**Results**

**Study population**

The total study population of 614 subjects comprised 302 men and 312 women, whose age averaged 51.2 \( \pm \)13.5 years, body mass index 26.3 \( \pm \)4.6 kg/m\(^2\) and the mean of five conventional blood pressure measurements 131 \( \pm \)18/82 \( \pm \)11 mmHg. We excluded 30 patients with previous myocardial infarction (\( n = 8 \)), diabetes (\( n = 21 \)), or both (\( n = 1 \)). For the analyses in the supine position, an additional 35 recordings had to be eliminated for the following reasons: no or too short registrations in four; arrhythmias or artefacts, or both, which could not be satisfactorily eliminated in 16, or breathing frequency below 0.15 Hz in 15 subjects. The characteristics of the 549 subjects who remained for the analysis of data in the supine position are given in Table 1, according to whether they were normotensive (\( n = 337 \)), hypertensive with conventional systolic blood pressure \( \geq \)140 mmHg or diastolic pressure \( \geq \)90 mmHg without antihypertensive therapy (\( n = 128 \)), or because they were on antihypertensive medication (\( n = 84 \)). Approximately half of the normotensives (55%) and half of the hypertensives (48%) were

**Table 1 Characteristics of the study population**

<table>
<thead>
<tr>
<th></th>
<th>Normotensives</th>
<th>Untreated</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>337</td>
<td>128</td>
<td>84</td>
</tr>
<tr>
<td>Men/women</td>
<td>152/185</td>
<td>76/62</td>
<td>34/50</td>
</tr>
<tr>
<td>Age (years)</td>
<td>46.8 ( \pm )11.9</td>
<td>52.4 ( \pm )13.3*</td>
<td>60.0 ( \pm )12.2*</td>
</tr>
<tr>
<td>Body mass index (kg/m(^2))</td>
<td>25.4 ( \pm )4.0</td>
<td>27.0 ( \pm )5.2*</td>
<td>27.8 ( \pm )5.9*</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conventional</td>
<td>121.4 ( \pm )9.6</td>
<td>144.2 ( \pm )15.6*</td>
<td>143.2 ( \pm )20.2*</td>
</tr>
<tr>
<td>daytime</td>
<td>121.1 ( \pm )9.1</td>
<td>130.7 ( \pm )11.8*</td>
<td>130.2 ( \pm )13.5*</td>
</tr>
<tr>
<td>night-time</td>
<td>103.1 ( \pm )9.1</td>
<td>112.3 ( \pm )11.5*</td>
<td>115.4 ( \pm )14.8*</td>
</tr>
<tr>
<td>24 h</td>
<td>114.6 ( \pm )8.5</td>
<td>123.8 ( \pm )10.4*</td>
<td>125.3 ( \pm )13.2*</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conventional</td>
<td>77.8 ( \pm )7.5</td>
<td>92.2 ( \pm )9.2*</td>
<td>83.7 ( \pm )11.2*</td>
</tr>
<tr>
<td>daytime</td>
<td>76.0 ( \pm )7.1</td>
<td>80.9 ( \pm )8.6*</td>
<td>78.1 ( \pm )8.5*</td>
</tr>
<tr>
<td>night-time</td>
<td>59.3 ( \pm )7.1</td>
<td>65.6 ( \pm )8.3</td>
<td>64.3 ( \pm )9.3</td>
</tr>
<tr>
<td>24 h</td>
<td>69.3 ( \pm )6.5</td>
<td>74.9 ( \pm )7.2*</td>
<td>73.1 ( \pm )7.6*</td>
</tr>
</tbody>
</table>

Values are means \( \pm \) SD. \( P \)-values for intergroup comparisons from one-way analysis of variance.

\* \( P \leq 0.05 \) for the comparison with normotensives; \( ^{\dagger} \) \( P \leq 0.05 \) for the comparison with untreated hypertensives.
women. However, whereas 49% of the hypertensive women were treated with antihypertensive drugs, only 31% of the men were on therapy. Treatment consisted of diuretics (45%), beta blockers (61%), calcium channel blockers (24%), angiotensin converting enzyme inhibitors (8%) and/or centrally acting drugs (6%); 64% of the patients were on monotherapy. Hypertensives were older than normotensives and had higher body mass index. Conventional and ambulatory blood pressures were similar in treated and untreated patients, except for the higher conventional and daytime diastolic pressure in those without therapy. Ambulatory blood pressure monitoring was successful in 528 of the 549 patients. All ambulatory blood pressures were significantly related to conventional blood pressure ($P < 0.001$). The correlation coefficients amounted to 0.57, 0.54 and 0.51, respectively, for 24 h, daytime and night-time systolic pressure, and to 0.44, 0.44 and 0.39, respectively, for the corresponding diastolic pressures.

An additional 34 subjects had to be excluded from the analyses of the orthostatic changes because their recordings in the standing position were not suitable for analysis for the following reasons: no or too short recording in nine; arrhythmias or artefacts in 10, and respiration at low frequency in 15. The results on HRV recording in nine; arrhythmias or artefacts in 10, and analysis for the following reasons: no or too short

### Heart rate and heart rate variability according to conventional blood pressure category

Table 2 summarizes the crude results in the three groups of subjects. In the supine position, the LF : HF ratio was significantly higher in untreated hypertensives than in normotensives, related to greater (relative) LF power and lower HF power, whereas heart rate tended to be higher in these hypertensives. The differences in heart rate and in RR interval between untreated hypertensives and normotensives became significant ($P < 0.01$) after adjustment for age, gender and body mass index. Figure 1 shows that the differences in LF and HF power and in their ratio, between normotensives and untreated hypertensives, remained significant after adjustment for these demographic and anthropometric characteristics. In the standing position, the unadjusted results did not differ between normotensives and untreated hypertensives (Table 2); after adjustment for age, gender and body mass index, absolute LF power and the LF : HF ratio were higher in the untreated hypertensives (Fig. 1). The changes from the supine to the standing position expressed as standing : supine ratios were significant for each variable within each group ($P < 0.005$), except for the absolute LF power in untreated hypertensives ($P = 0.08$). Table 2 also shows that treated hypertensives differed from normotensives, untreated hypertensives, or from both, in several respects.

### Relationships of blood pressure with heart rate and heart rate variability in the supine position

Table 3 gives the partial correlation coefficients of the relationships of heart rate and HRV with various blood pressure measurements, after controlling for age, gender, body mass index and antihypertensive drug class. Heart rate was positively related to systolic and diastolic conventional blood pressure, whereas total and

### Table 2 Mean and total power of the RR interval and results from power spectral analysis in normotensives, untreated hypertensives and hypertensives under treatment

<table>
<thead>
<tr>
<th></th>
<th>Supine</th>
<th></th>
<th>Standing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normotensives</td>
<td>Untreated</td>
<td>Treated</td>
<td>Normotensives</td>
</tr>
<tr>
<td>Number</td>
<td>337</td>
<td>128</td>
<td>84</td>
<td>323</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>64.9 ± 9.5</td>
<td>67.1 ± 9.0</td>
<td>62.6 ± 10.3</td>
<td>80.8 ± 11.3</td>
</tr>
<tr>
<td>RR interval (ms)</td>
<td>944 ± 140</td>
<td>910 ± 113</td>
<td>986 ± 174</td>
<td>760 ± 112</td>
</tr>
<tr>
<td>Total power (log ms$^2$)</td>
<td>3.11 ± 0.39</td>
<td>3.03 ± 0.38</td>
<td>2.95 ± 0.45</td>
<td>2.87 ± 0.39</td>
</tr>
<tr>
<td>(geometric mean)</td>
<td>(1297)</td>
<td>(1069)</td>
<td>(901)</td>
<td>(741)</td>
</tr>
<tr>
<td>Partial power (log ms$^2$)</td>
<td>2.91 ± 0.44</td>
<td>2.79 ± 0.41</td>
<td>2.72 ± 0.49</td>
<td>2.61 ± 0.44</td>
</tr>
<tr>
<td>(geometric mean)</td>
<td>(786)</td>
<td>(623)</td>
<td>(530)</td>
<td>(400)</td>
</tr>
<tr>
<td>Low-frequency component</td>
<td>absolute power (log ms$^2$)</td>
<td>2.35 ± 0.52</td>
<td>2.33 ± 0.49</td>
<td>2.08 ± 0.60</td>
</tr>
<tr>
<td>(geometric mean)</td>
<td>(224)</td>
<td>(214)</td>
<td>(119)</td>
<td>(187)</td>
</tr>
<tr>
<td>relative power (%)</td>
<td>33.5 ± 17.1</td>
<td>38.7 ± 16.8</td>
<td>27.7 ± 16.0</td>
<td>52.1 ± 20.7</td>
</tr>
<tr>
<td>High-frequency component</td>
<td>absolute power (log ms$^2$)</td>
<td>2.44 ± 0.56</td>
<td>2.20 ± 0.54</td>
<td>2.23 ± 0.61</td>
</tr>
<tr>
<td>(geometric mean)</td>
<td>(275)</td>
<td>(160)</td>
<td>(171)</td>
<td>(53.4)</td>
</tr>
<tr>
<td>relative power (%)</td>
<td>40.5 ± 19.2</td>
<td>31.4 ± 18.6</td>
<td>38.1 ± 20.7</td>
<td>185 ± 14.1</td>
</tr>
<tr>
<td>LF : HF ratio (log)</td>
<td>0.088 ± 0.458</td>
<td>0.126 ± 0.426</td>
<td>0.157 ± 0.481</td>
<td>0.544 ± 0.533</td>
</tr>
<tr>
<td>(geometric mean)</td>
<td>(0.82)</td>
<td>(1.34)</td>
<td>(3.07)</td>
<td>(3.50)</td>
</tr>
</tbody>
</table>

Values are means ± SD; geometric means are given between brackets. $P$-values for intergroup comparisons from one-way analysis of variance: $^* P < 0.05$ for the comparison with normotensives; $^+ P < 0.05$ for the comparison with untreated hypertensives. The standing-to-supine ratios are significant for each variable within each group ($P < 0.005$), except for the absolute LF power in untreated hypertensives ($P < 0.08$), bpm, beats per minute; RR, risk ratio.
partial power showed inverse relationships. Also the LF:HF ratio was positively related to these blood pressures, based on a positive association with LF power, when expressed in normalized units and on inverse relationships with HF power. However, the frequency components of HRV were not significantly related to systolic 24 h, daytime or night-time blood pressure, and the significant associations with diastolic ambulatory pressure were in general weaker than with conventional pressure. Finally, the difference between conventional and daytime blood pressure was inversely related to HF power and positively to normalized LF power and to the LF:HF ratio. Results were similar with additional adjustment for smoking, alcohol consumption and physical activity, or when treated hypertensive patients were not included in the regression analyses.
Figure 2 shows the LF:HF ratio, adjusted for age, gender, body mass index, drug class and daytime mean blood pressure, in three tertiles of the difference between conventional and daytime blood pressure, both for systolic and diastolic pressure. The LF:HF ratio was significantly higher in the subjects with the largest blood pressure difference than in the other two tertiles.

Relationships of blood pressure with the orthostatic response of heart rate and heart rate variability
As shown in Table 4, the inverse relationships between conventional blood pressure and the standing:supine ratios of heart rate, normalized LF power and the LF:HF ratio indicate that the orthostatic increases of these variables are less pronounced in subjects with higher than with lower blood pressure, whereas the positive relationship for HF power points to a less pronounced decrease of HF power at higher blood pressure. These associations were in general not very different when ambulatory blood pressure was used in the analyses, and there were no significant relationships between the differences between conventional and daytime pressure and the orthostatic responses of heart rate and HRV. Additional adjustment for lifestyle factors did not influence the results.

Discussion
The principal aim of the present population-based study was to assess the independent relationships of...
Heart rate and the spectral components of HRV as indices of autonomic nervous function, assessed at supine rest and in response to standing, with both conventional blood pressure measured by an investigator, and with ambulatory blood pressure outside the laboratory environment. Relationships were also sought with the difference between conventional and daytime pressure, which at least partly reflects the response of blood pressure to the measurement conditions or the so-called white coat effect.

Heart rate and heart rate variability at rest
In order to assess heart rate and HRV in as basal conditions as possible, the analysis was performed at the end of a 15 min registration period, during which the investigator had withdrawn from the room and which was preceded by another 10 min at supine rest. Despite these precautions and the fact that the resting heart rate of \( 63 \pm 10 \) beats/min in men and of \( 67 \pm 9 \) beats/min in women suggest relaxed conditions, environmental influences on heart rate and HRV cannot be totally excluded. Resting heart rate, LF power and the LF: HF ratio were positively, and the HF component inversely, related to conventional blood pressure, both when untreated hypertensives were compared to normotensive subjects, and in the regression analyses, with or without inclusion of the patients on antihypertensive therapy. In the latter approach, the possible influence of different drug classes on heart rate and HRV was accounted for by inclusion of a dummy variable for each class separately in the multivariable analyses. A number of previous studies have compared heart rate and the spectral components of HRV in hypertensive patients and normal volunteers [7–18], or have assessed associations with blood pressure in a population-based approach [19–21], using clinic or conventional blood pressure measurements. The results have been variable. For example, the LF: HF ratio was reported to be higher [7,10,18] or lower [17] in hypertensives than in normotensives, or not different [11–13,20,21] according to blood pressure. Divergent results may be ascribed to a number of factors, first of all methodological differences regarding the computation and expression of the indices of HRV. Review of the literature [7–21] and our own data suggest that results may differ according to whether the frequency components are expressed in absolute or in normalized units. With regard to the method for spectral analysis, some authors have applied autoregressive modelling [7,8,12,13,16–19], whereas others used fast Fourier transform [9,10,14,15,20,21]. We observed that the strengths of the relationships between HRV and blood pressure were similar for these two commonly used methods, which suggests that divergent results in the literature with regard to these relationships can probably not be attributed to the spectral method. This does not mean that these methods have identical power of analysing the cardiovascular rhythms and would yield identical results in individual subjects. Both systematic differences and substantial individual differences were observed when the same recordings were analysed by both ARM and FFT [27]. Most authors analysed short-term RR interval registrations under standardized laboratory conditions, but some [8,9,14,21] used 24 h electrocardiographic recordings, which are influenced by variations in posture, physical and mental activity and by sleep. Furthermore, the small sample size in a number of clinical studies may have precluded the detection of intergroup differences, particularly when considering our findings that the variance of heart rate and HRV which can be explained by conventional blood pressure is 4% at the most. Finally, conventional blood pressure may have been influenced to a variable extent by the measurement conditions, particularly the ‘white-coat’ effect on blood pressure [22].

Ambulatory blood pressure monitoring was not applied in the previous reports [7–21] to characterize the blood pressure of the studied subjects. We observed that resting heart rate and HRV were not or only weakly related to 24 h, daytime and night-time ambulatory blood pressure. Several reasons can be invoked to explain the stronger relationships with conventional than with ambulatory blood pressure. The measurement of blood pressure by the investigator may have led to stimulation of the sympathetic nervous system, the so-called ‘white-coat’ effect, so that relationships with indices of HRV, which are themselves under the influence of the autonomic nervous system, are to be expected. Although care was taken to assess HRV in as basal conditions as possible and with avoidance of smoking, caffeine and heavy meals, an effect of the laboratory and environmental conditions on HRV cannot be totally excluded. Guzzetti et al. [8] found that the clinical setting led to more elevated LF component as compared to the ambulant condition. Lantelme et al. [33] observed a modification of the sympathovagal balance, characterized by sympathetic predominance, but this occurred during the blood pressure measurement by the physician.

Ambulatory blood pressure monitoring overcomes several disadvantages of clinic, conventional or casual blood pressure measurements. Main advantages of ambulatory monitoring are the large number of measurements during 24 h versus the usually small number of pressures during a short selected period of the day and the fact that it is devoid of the blood pressure response to the presence of an investigator or the ‘white-coat’ effect, so that ambulatory blood pressure is likely to be closer to the subject’s usual or true blood pressure.

The results could therefore suggest that the role of the
autonomic nervous system is less important in hypertension than derived from conventional blood pressure measurements. On the other hand, ambulatory blood pressure is influenced by lifestyle characteristics, psychoemotional stresses and variable physical and mental activity during the day and by possible sleep disturbances during the night. Furthermore, ambulatory blood pressure was not monitored on the day of the laboratory visit in this epidemiological study, but ambulatory blood pressure is known to be highly reproducible with regard to the average daytime and night-time pressures [34]. The finding that associations between blood pressure and basal HRV are stronger for conventional than for ambulatory blood pressure suggest that the measurement conditions play a pivotal role in these relationships.

Orthostatic response of heart rate and HRV
The fact that both conventional and ambulatory blood pressures significantly predict the orthostatic changes of heart rate and HRV, and that these changes are not related to the difference between conventional and daytime blood pressure, suggest that the blunting of the orthostatic response is truly related to blood pressure. Furthermore, our results are consistent with data from the literature, in which most [7,8,12,13,17,18] authors with few exceptions [16,19] found that the reduction of HF power and the increases of LF power and the LF:HF-ratio on sitting, standing or tilting are ascribed to the effects of the measurement conditions play a pivotal role in these relationships.

Interpretation of the findings
Spontaneous beat-to-beat fluctuations of heart rate are in the main, the expression of the continuous action of neural control mechanisms. The HF component is considered to mainly estimate the degree of cardiac vagal modulation, whereas the LF component comprises both sympathetic and vagal oscillations [4–6]. The LF:HF ratio has been proposed as a quantification of the sympathovagal balance [5]. The present study indicates that there are small (diastolic pressure) or no (systolic pressure) independent associations between these indices of autonomic functioning measured at rest and ambulatory blood pressure, both during night and day. Therefore, the observed relationships with conventional blood pressure which suggest reduced vagal modulation and increased sympathetic modulation at higher blood pressure may at least partly be ascribed to the effects of the measurement conditions.

The reduced HF power on standing, the increase of the LF component, at least when normalized for the reduced overall heart rate variability, and the increased LF:HF ratio are compatible with vagal withdrawal and sympathetic stimulation. These orthostatic autonomic changes appear to be blunted at higher blood pressure, both when measured conventionally and during ambulation, so that they appear to be influenced by blood pressure per se. Impairment of the baroreceptor control of heart rate in hypertension may play a role in the lesser autonomic response to the postural change [35].

The results show that spectral analysis of HRV is of value in identifying sympathovagal changes in cardiovascular diseases such as hypertension.

Acknowledgements
The authors gratefully acknowledge the assistance of N. Auscello, L. Gijsbers, A. Hermans, J. Romont and S. Van Hulle. R.F. is holder of the Professor A. Amery Chair in Hypertension Research, founded by Merck Sharp and Dohme (Belgium).

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