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A Dampening Effect of Pulse Interval Variability on Blood Pressure Variations with Respect to Primary Variability in Blood Pressure during Exercise

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Summary

The correlation between baroreflex sensitivity (BRS) and the spectrum component at a frequency of 0.1 Hz of pulse intervals (PI) and systolic blood pressure (SBP) was studied. SBP and PI of 51 subjects were recorded beat-to-beat at rest (3 min), during exercise (0.5 W/kg of body weight, 9 min), and at rest (6 min) after exercise. BRS was determined by a spectral method (a modified alpha index technique). The subjects were divided into groups according to the spectral amplitude of SBP at a frequency of 0.1 Hz. The following limits of amplitude (in mm Hg) were used: very high ≥ 5.4 (VH); high $5.4 > H \geq 3$ (H); medium $3 > M \geq 2$ (M), low < 2 (L). We analyzed the relationships between 0.1 Hz variability in PI and BRS at rest, during the exercise and during recovery in subgroups VH, H, M, L. The 0.1 Hz variability of PI increased significantly with increasing BRS in each of the groups with identical 0.1 Hz variability in SBP. This relationship was shifted to the lower values of PI variability at the same BRS with a decrease in SBP variability. The primary SBP variability increased during exercise. The interrelationship between the variability of SBP, PI and BRS was identical at rest and during exercise. A causal interrelationship between the 0.1 Hz variability of SBP and PI, and BRS was shown. During exercise, the increasing primary variability in SBP due to sympathetic activation was present, but it did not change the relationship between variability in pulse intervals and BRS.

Key words

Baroreflex sensitivity • Spectral analysis • Heart rate variability • Blood pressure variability • Exercise

Introduction

The arterial baroreflex is a powerful mechanism of fundamental importance for cardiovascular homeostasis. Its impairment may play an adverse role in several diseases (Sleight 1991, Semrád *et al.* 1999, Honzíková *et al.* 2000a,b). Though a complex response of the controlling mechanisms mediated by baroreceptors includes the regulation of the heart and of the tone of resistance and capacitance vessels (Gribbin *et al.* 1971, Sleight 1991, Honzíková 1992, 2001), the sensitivity of the baroreceptor-heart rate reflex (BRS) is studied most frequently.

The mostly used methods quantify BRS through an external stimulus to the subject, e.g. administration of a vasoactive drug, a neck chamber technique, Valsalva maneuver, head-up tilting, a lower body negative pressure, and others. The advantages and limitations of

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eleven of these laboratory methods were discussed recently (Parati *et al.* 2001). Moreover, the dynamic features of a spontaneous control of the heart were investigated by methods based on the analysis of a spontaneous variability of systolic blood pressure (SBP) and heart rate or pulse intervals (PI). Techniques of BRS determination based on evaluation of a spontaneous SBP and PI variability were developed for time and frequency domain (Persson *et al.* 2001). The data obtained in several studies proved that different techniques provide comparable but not identical information on BRS. It is of importance from a clinical point of view that identical critical values were determined in the prediction of the risk of cardiac death by the phenylephrine and spectral method (La Rovere *et al.* 1998, Honzíková *et al.* 2000a,b). Concerning the time course of BRS during a dynamic test, comparable changes of BRS were detected for example by five methods (sequence method, modified complex demodulation, spectral alpha index, LP model technique and wavelet technique) during exercise (Krtička *et al.* 2000, 2001).

In many studies which evaluated the changes in autonomic regulation under various states of activation or disease (hypertension, myocardial infarction, diabetes mellitus, and heart failure), heart rate variability was used as a measure of autonomic control of the heart. Besides these typical diseases, heart rate variability has newly been used in very different diagnoses, e.g. subarachnoid hemorrhage (Venkatesh *et al.* 2002), as a marker of a cardiotoxic side effect of antimalignant therapy by anthracyclines (Hrstková *et al.* 2001), or abnormal autonomic function in erythrophobia (Laederach-Hofmann *et al.* 2002). It was generally accepted that high vagal tone was associated with high heart rate variability, but this relationship is not causal. Small changes in vagal tone can be associated with different changes of heart rate variability (Honzíková *et al.* 1988). Many factors may take part in this effect, such as respiratory rate and depth (Hirsch and Bishop 1981, Honzíková *et al.* 1992, Javorka *et al.* 2001, 2002, Hoyer *et al.* 2002), and sympathetic activity, which is taken into account in studies comparing the ratio of variability in two spectral frequency ranges (low and high) as LF/HF (Pagani *et al.* 1995, Javorka *et al.* 1999). Several studies have shown that PI variability is related to BRS (Závodná *et al.* 2001), and plays an antioscillatory role in the regulation of blood pressure (Kardos *et al.* 1995, Krtička *et al.* 2001).

A detailed study of the interrelationship between the heart rate variability, blood pressure variability and baroreflex control of the heart rate needs to minimize other factors influencing the heart rate variability. Therefore, it seems useful to summarize mechanisms which interact in the control of heart rate at a frequency of 0.1 Hz and at a respiratory frequency.

The majority of mechanisms of variability in circulation have been known for decades from experiments in animals. In the respiratory range, e.g. high frequency range (HF) – usually 0.15-0.5 Hz, respiratory movements elicit blood-pressure waves and the respiratory sinus arrhythmia is mediated by baroreflex (Haymet and Closkey 1975) and/or through stimulation of receptors in the atria (Koepchen 1962). On the other hand, it was proven that respiratory movements are not necessary for respiratory arrhythmia. The fluctuations of heart rate with a time course similar to respiration can be seen at the onset of breath hold and before the termination of a prolonged breath hold (Valentinuzzi and Geddes 1974, Javorka *et al.* 2001). The origin of this fluctuation is in the central irradiation of activity from the respiratory centers to the cardioinhibitory center. There is also a reflex inhibition of the cardioinhibitory center by the mechanoreceptors in the thorax wall and in the lungs. Summarizing this information we see that the respiratory sinus arrhythmia is elicited by the parasympathetic control of the sinus node (an additive direct influence of venous return changes on sinus node can be involved), but there are minimally four inputs into the cardioinhibitory center which modulate respiratory sinus arrhythmia with a different time shift and gain (Honzíková 2001).

Different mechanisms are involved in the mid-frequency range of variability in circulation. Blood pressure oscillates relatively regularly at a frequency near to 0.1 Hz. Besides central modulation of the vasomotor activity at this frequency, several theories explain the role of the baroreflex in these waves of blood pressure. Sayers (1973) introduced the theory that the spontaneous feedback rhythm is centered at the frequency of 0.1 Hz due to time constants and delay in the feedback circuits. This theory was accepted by many authors as was documented by Saul (1990). Another plausible theory was suggested by Wesseling *et al.* (1983), which is based on two facts. The smooth muscles of blood vessels are not able to follow rapid changes of a vasomotor nerve activity. Therefore, the oscillations of peripheral resistance at frequencies higher than 0.066 Hz are attenuated (Peňáz 1970). The low frequency oscillations of peripheral resistance are compensated by means of the

baroreflex. Thus slow and fast oscillations are eliminated and the 0.1 Hz peak remains. The primary oscillations of blood pressure elicit changes of cardiac intervals and the gain between variability in SBP and pulse intervals at 0.1 Hz corresponds very closely to BRS. However, both autonomic nerves, sympathetic and parasympathetic, may transmit the control effect on the sinus node. Nevertheless, the oscillations of SBP and PI at a frequency of 0.1 Hz seem to be the most suitable frequency range for studying the role of BRS for SBP and PI variability (Honzíková 1992, Honzíková *et al.* 1992).

In this study, we have analyzed the interrelationship between the variability of PI and SBP together with BRS at a frequency of 0.1 Hz with the aim to separate the dampening effect of pulse interval variability on blood pressure oscillations from an opposite effect of primary variability in blood pressure on the variability in pulse intervals. We have studied whether the interrelationship between the PI and SBP variability and BRS is affected by exercise. Such an analysis should contribute to a deeper understanding of the influence of a primary sympathetic control of resistance vessels on the relationship between the variability in PI and BRS.

Methods

Subjects and protocol

Blood pressure was recorded beat-to-beat in finger arteries (Finapres Ohmeda 2300) in 51 healthy subjects (aged 21-22 years) for 3 min at rest, 9 min during exercise (0.5 W/kg of body weight), and 6 min in recovery period. Controlled breathing (20 breaths per min) was used at rest and during recovery periods with respect to the importance of high-frequency paced breathing in spectral baroreflex sensitivity assessment (Frederiks *et al.* 2000).

The study was approved by the Ethics Committee and informed consent was obtained from each subject.

The primary signal used was the blood pressure waveform signal from the output of the Finapres, sampled at 250 Hz sampling frequency and stored on a PC hard disk. From the stored signal, the sequence of SBP, DBP and PI triads of subsequent heart beats were extracted.

Data preprocessing

These signals were sampled irregularly, beat-to-beat. As a consequence of this irregular sampling, the spectra contained components of up to several Hz. Prior to further processing the irrelevant and spurious high frequency components had to be suppressed. Thus the original signals were interpolated by cubic splines, resampled at 10 Hz, and then filtered by a low-pass filter with a cut-off frequency of 0.8 Hz. Finally the sampling frequency was reduced to 2 Hz.

Spectral analysis, baroreflex sensitivity assessment

The power spectra of SBP and PI were calculated. BRS (ms/mmHg) was determined by a modified spectral method, which was previously described as a modified alpha index technique (Krtička *et al.* 2000).

The alpha index method is based on the spectral decomposition of PI and SBP signals and a comparison of their spectral components. Both these signals were processed sequentially, segment by segment, from the beginning to the end, in half-second steps. In the procedure presented, segments of 70-second length, i.e. with 140 samples, were used.

Each segment was processed using the following procedure. The linear trend was removed and the segment was then multiplied by the Blackman window (see Fig. 1a). To obtain a better interpolation of the spectrum, the segment was extended to 2048 samples, add-on samples being filled with zeros. This gave the 1/2048 = 0.488 mHz frequency resolution. Using the fast Fourier transform (FFT), the amplitude and phase spectra of SBP and PI were calculated. Moreover, the product P of SBP and PI spectral amplitudes, called power, was calculated.

In the vicinity of frequencies where the power had its maxima, the spectra of both signals were examined. If the maxima at the identical frequency were present in both spectra – those of PI and SBP, these components were selected (see Fig. 1b). The frequencies together with the magnitudes and phases of the selected PI and SBP spectral components were recorded. The parameters of the selected components were attached to the center time of the segment. The frequencies of selected spectral components were arranged in a time-frequency map (see Fig**.** 1c), in which the x-axis corresponded to the time and the y-axis represented the frequencies of the selected conjoint components. Each point showed the time and the frequency at which the PI spectrum and SBP spectrum had their common maxima. Only those components whose amplitude was higher than 3 % of the highest component were taken into account.

Of the couples passed, those with a frequency near 0.1 Hz were selected manually. These selected components are given in Figure 1c (marked by bold points which run in bold curves). From the components selected, BRS (Fig. 2c) was determined as the ratio of PI and SBP amplitudes (Fig. 2e). Moreover, from the phase-shift between the PI and SBP, the delay dt between the selected components was calculated (Fig. 2f). The product P of SBP and PI spectral amplitudes was also calculated (Fig. 2d).

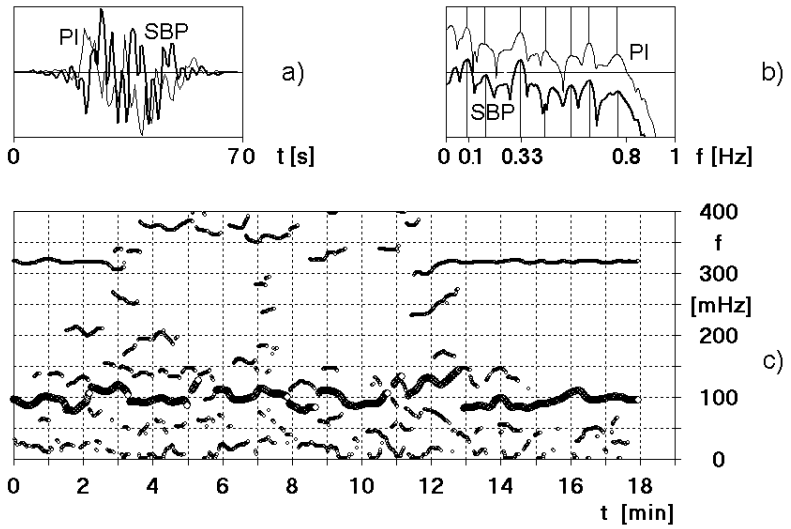

Fig. 1. *Procedure of selection of the spectral components of pulse interval (PI) and systolic blood pressure (SBP) signals. a) Segments of PI (thin line) and SBP (thick line) signals (70 s duration) multiplied by Blackman window. b) Spectra of signals shown in panel a) of this Figure with marked maxima present in both spectra. c) Time-frequency map of determined components. Thick lines mark components with frequencies in the neighborhood of 0.1 Hz, selected for baroreflex sensitivity (BRS) determination.*

Statistics

The time course of SBP, DBP, PI, variability of these parameters at a frequency of 0.1 Hz, and BRS were compared. Mean values and S.D. were calculated for periods with minimal transients: 0.5-2.5 min of rest (R1), 3.5-7.5 min of recording for the first half of exercise (E1), 7.5-11.5 min of recording for the second half of exercise (E2), and 12.5-17.5 min during the recovery period (R2). The correlation between BRS and the variability of SBP and PI at 0.1 Hz in individual experimental periods was evaluated by Spearman's correlation coefficient. The significance of the differences in the values of cardiovascular parameters between the experimental periods was tested by the Wilcoxon test.

The subjects were divided into groups according to the spectral power of SBP at a frequency of 0.1 Hz. The following limits of amplitude (in mmHg) were used: very high ≥ 5.4 (VH); high $5.4 > H \geq 3$ (H); medium $3 > M \geq 2$ (M), low < 2 (L). We analyzed the relationships between 0.1 Hz variability in PI and BRS at rest (R1) and during the first and the second half of exercise (E1, E2) and during recovery (R2) in subgroups VH, H, M, and L.

Results

The averaged curves of the time course of the changes of systolic and diastolic pressures and of the heart rate in 51 subjects (31 males, 20 females) confirmed a standard circulatory response to the exercise (Fig. 2a,b]. The heart rate reached its maximum within the first 30 s after the beginning of exercise, after which a mild decrease of the heart rate followed, and the steady state was reached in about two minutes. The systolic blood pressure increased more slowly and reached its maximum about 1 min after the beginning of the exercise, which was followed by a slow decrease of systolic blood pressure. The diastolic blood pressure decreased within seconds and returned to its original value in about one minute. BRS of individual subjects varied in time more or less periodically in all periods, at rest and during exercise (Fig. 2c). Not only the amplitude of BRS, but also the frequency, at which heart rate and blood pressure fluctuated, varied in time (Fig. 2d). The so-called 0.1 Hz frequency ranged between 0.07 and 0.12 Hz. The curve of the time course of BRS changes was similar to that of the pulse intervals, but it differed from the curves of systolic and diastolic blood pressures.

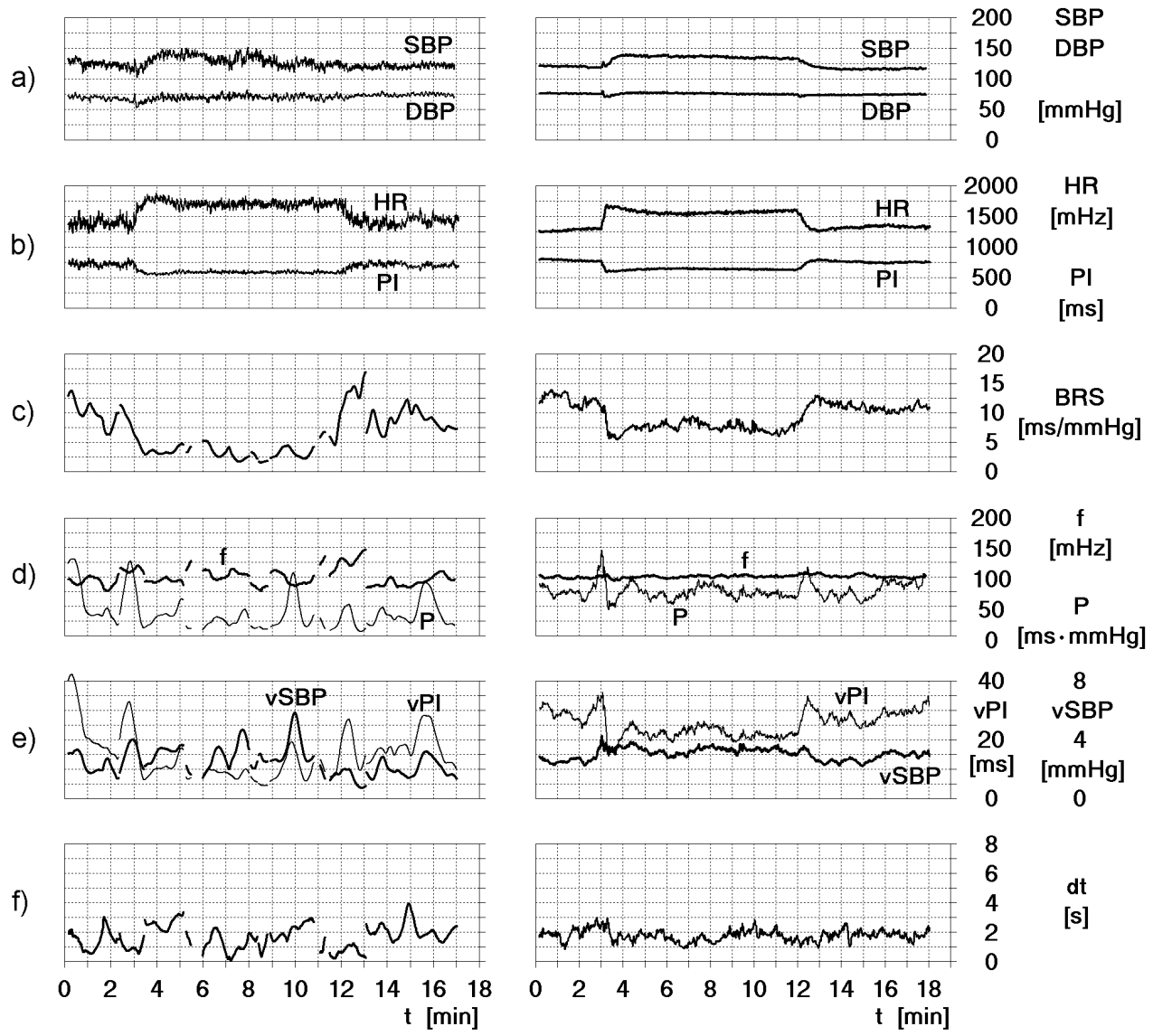

Fig. 2. *The time course of circulatory variables at rest and during exercise in an example (left) and the mean of 51 experiments (right). a) systolic and diastolic blood pressure (SBP and DBP); b) pulse intervals and their inverse, heart rate (PI and HR); c) baroreflex sensitivity (BRS); d) frequency at which BRS was determined (f) and power, i.e. the product of PI and SBP spectral component amplitudes (P); e) the time course of the selected spectral components at a frequency of 0.1 Hz of PI and SBP (vPI and vSBP); f) time-shift between vPI and vSBP spectral components at a 0.1 Hz frequency.*

The mean values of blood pressure, PI, BRS, and of the 0.1 Hz variability in SBP and PI, and the products of these variabilities in the whole group in each experimental period are given in Table 1. During exercise, a typical shortening of the mean pulse interval was associated with a SBP increase. Variability at a frequency of 0.1 Hz increased in SBP and decreased in PI. Our goal was to carry out the analysis that deals with interrelationships between 0.1 Hz components in SBP and PI, and BRS. At rest, BRS correlated positively with the 0.1 Hz variability in PI and negatively with the 0.1 Hz variability in SBP. The product of the amplitude of 0.1 Hz components in PI and SBP was independent of BRS (Table 2).

During exercise, when BRS significantly decreased, the 0.1 Hz component in SBP significantly increased (Table 1) and its correlation with BRS was weakened (Table 2). Because the 0.1 Hz component in PI strongly correlated with BRS even during exercise, a mild correlation occurred between the product of the amplitude of 0.1 Hz components in PI and SBP, and BRS (Table 2).

Table 1. Mean values and standard deviations of baroreflex sensitivity, blood pressure and pulse intervals and their variability in all subjects during the experiment.

Parameter	R1	E1	E2	R2
BRS [ms/mm Hg]	12.6 ± 5.2***	7.7 ± 4.5^{+++}	7.5 ± 4.3$^{\times\times\times}$	11.2 ± 4.6$^{\circ\circ\circ\#}$
SBP [mm Hg]	120.1 ± 13.0***	137.2 ± 19.2^{+++}	134.9 ± 18.9$^{\times\times\times\S\S}$	116.6 ± 13.6$^{\circ\circ\circ\#\#}$
DBP [mm Hg]	75.5 ± 9.9	76.6 ± 11.9^{++}	75.3 ± 12.8§§§	73.9 ± 11.9$^{\#\#\#}$
PI [ms]	782.2 ± 120.7***	636.9 ± 78.8^{+++}	635.6 ± 81.7$^{\times\times\times}$	757.5±114.3$^{\circ\circ\circ\#\#\#}$
0.1 Hz SBP[mm Hg]	2.5 ± 0.9***	3.1 ± 1.4^{++}	3.2 ± 1.6$^{\times\times\times}$	2.7 ± 0.9$^{\circ\#}$
0.1 Hz PI [ms]	27.3 ± 11.1***	20.9 ± 12.3^{+++}	20.6 ± 13.9$^{\times\times\times}$	27.5 ± 11.9$^{\circ\circ\circ}$
*0.1 Hz PI x SBP [ms*mm Hg]*	38.7 ± 25.2	39.9 ± 42.6^{+}	42.4 ± 65.2	43.5 ± 28.5$^{\circ\circ}$

*R1 vs. E1: ** $p<0.01$, *** $p<0.001$; E1 vs. R2: $^{+}p<0.05$, $^{++}p<0.01$, $^{+++}p<0.001$; E2 vs.R1: $^{\times}p<0.05$, $^{\times\times}p<0.01$, $^{\times\times\times}p<0.001$; R2 vs. E2: $^{\circ\circ}p<0.01$, $^{\circ\circ\circ}p<0.001$; R2 vs. R1: $^{\#}p<0.05$, $^{\#\#}p<0.01$, $^{\#\#\#}p<0.001$; E2 vs. E1: $^{\S\S}p<0.01$, $^{\S\S\S}p<0.001$. BRS, baroreflex sensitivity; SBP, systolic blood pressure; DBP, diastolic blood pressure; PI, pulse intervals; 0.1 Hz SBP, 0.1 Hz component of power spectrum of systolic blood pressure; 0.1 Hz PI, 0.1 Hz component of power spectrum of pulse intervals; 0.1 Hz PI x SBP, product of 0.1 Hz spectral components of blood pressure and pulse intervals. Periods of experiment: R1, rest; E1, first half of exercise; E2, second half of exercise; R2, recovery period.*

Table 2. Correlation of baroreflex sensitivity with 0.1 Hz variability in blood pressure and in pulse intervals.

Parameter	R1	E1	E2	R2
0.1 Hz SBP [mmHg]	–0.4329**	–0.2843*	–0.3441*	–0.2539
0.1Hz PI [ms]	0.4744***	0.7226***	0.7298***	0.6766***
*0.1 Hz PI x SBP [ms*mmHg]*	0.0685	0.3368*	0.3338*	0.3233*

*Abbreviations see in Table 1. *$p<0.05$, **$p<0.01$, ***$p<0.001$*

During the recovery period, changes in mean values of all parameters were shifted to the resting values, but full recovery was not reached. Mean PI was still shortened, i.e. the tonic parasympathetic activity did not completely return to the resting value or sympathetic activation of sinus node was still increased. Quite different response could be seen in blood pressure. SBP and DBP were lower than at rest. Variability of PI at the frequency of 0.1 Hz was as high as at rest, but variability of SBP was somewhat higher. Whereas PI variability highly correlated with BRS, SBP variability was BRS-independent. A higher variability and interindividual differences of variability in PI and SBP in the recovery period were associated with an increase in the product of the amplitudes of 0.1 Hz variability in SBP and PI, which correlated with BRS.

The cardiovascular changes in 0.1 Hz variability during exercise were not uniform. Analyzing the differences in changes of SBP and PI variability between the subjects in response to exercise, we found the following changes. There were several most frequent changes. Response 1 – An increase in SBP variability together with a decrease in PI variability (22 subjects). In 21 of them BRS also decreased. Response 2 – In 14 subjects, the variability of both PI and SBP was increased. In this group, BRS was decreased in 11 subjects. Response 3 – In 15 subjects, the variability in both SBP and PI decreased together with a decreased BRS. We did not find a decrease in SBP variability together with an increase in PI variability in any subject during exercise. It is generally supposed that BRS decreases during exercise. Although a mild BRS increase occurred in 4 subjects (on average by 12 %), the predominant response was a decrease of BRS (by 45 % on average in other subjects).

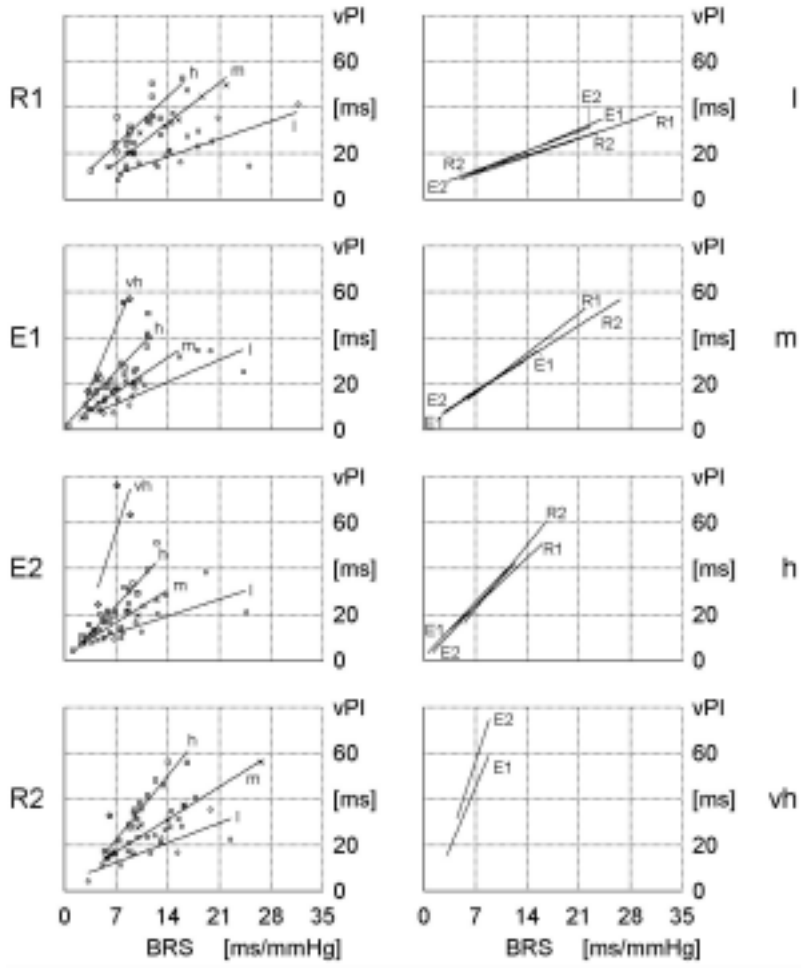

Fig. 3. *Relationship between the variability in pulse intervals at a frequency of 0.1 Hz (vPI) and BRS. From top to bottom divided according to: left - experimental periods; right - variability in SBP. Abbreviations: R1, at rest; E1, E2, first and second half of exercise; R2, recovery; l, low variability of SBP; m, medium variability of SBP; h, high variability of SBP; vh, very high variability of SBP.*

In the next step, we analyzed the interrelationship among BRS, the amplitude of 0.1 Hz components in PI and in SBP. The correlation between BRS and 0.1 Hz variability in PI was tested in subgroups with a different 0.1 Hz variability in SBP in each experimental period. The 0.1 Hz variability of PI increased significantly with increasing BRS in each of the subgroups with the identical 0.1 Hz variability in SBP in each experimental period (Fig. 3 R1, E1, E2, and R2, left). This relationship was shifted to the lower values of PI variability at the same BRS with a decrease in SBP variability. The slope of the regression lines of the relationship between BRS and PI-variability increased significantly with increasing SBP-variability ($p<0.01$) in each experimental period. However, it was identical for each range of SBP-variability in all periods of the experiment. This means that the interrelationship among the variability of SBP, PI and BRS was identical at rest and during exercise (Fig. 3 L, M, H, VH, right), but the number of subjects in individual subgroups differed (Table 3).

Table 3. Numbers of subjects in groups L, M, H and VH of intervals R1, E1, E2 and R2.

	Limits [mm Hg]	**R1**	**E1**	**E2**	**R2**
L	< 2	17	10	13	12
M	2-2.9	17	20	11	23
H	3-5.3	17	17	24	15
VH	> 5.4	0	4	3	1

Discussion

It was found in previous studies that baroreflex sensitivity decreases with age (e.g. Sleight 1991, Semrád *et al.* 1998) and is dependent on the value of blood pressure in different age groups (Gribbin *et al.* 1971). In older people, the value of resting BRS can be influenced by different mechanisms: by a shift of the working point related to blood pressure or by diminished compliance elicited by the hypertrophy of the wall of the carotic sinus caused by a higher pressure (De Vries *et al.* 2000). In heart failure, an increased activity of aldosterone diminishes the baroreceptor sensitivity by activation of sodium-potassium ATPase (Wang *et al.* 1991). The cause of the decreased BRS after myocardial infarction is not clear enough, although its importance for the prediction of cardiac death has been proven (La Rovere *et al.* 1998, Honzíková *et al.* 2000b).

Baroreflex sensitivity also decreases during different types of stress. Trophic changes cannot play a role during a short period of physical exercise. It is supposed that a BRS decrease during exercise is of central origin. The fact that the change of PI preceded the change of blood pressure showed that a shift of the working point of blood pressure regulation does not play any role in the decrease of BRS.

In our study, baroreflex sensitivity was determined by a modified alpha index technique (Krtička *et al.* 2000). It was shown that BRS varies in time even under resting steady-state conditions and that the frequency of 0.1 Hz of these variations is also not stable. Even if our analysis cannot give an explanation of the origin of this instability of BRS in time, we suppose that central mechanisms are involved in these changes. Moreover, the phase-shift between the PI and SBP variability at 0.1 Hz and the delay between these variabilities were not stable. On the basis of our analysis, we cannot give an explanation for these instabilities. The transient superposition of the additive mechanism of heart rate and blood pressure variability, which are dominantly effective in other frequency ranges, can be speculated.

A complex analysis of the relationship between BRS and the amplitude of the 0.1 Hz spectral components of variability in PI and SBP has brought a new insight into the understanding of the causality between these variables. Our findings of a positive correlation between BRS and PI variability at a frequency of 0.1 Hz and a negative correlation between BRS and SBP variability at this frequency at rest indicated that a high BRS at rest dampened the blood pressure variability by changes in PI and therefore also the product of 0.1 Hz components in PI and SBP was independent of BRS. During exercise, when BRS was lower than at rest, the effect of PI variability on blood pressure stabilization was not high enough to compensate for blood pressure variability. Thus both the amplitude of the 0.1 Hz component in PI and the product of the 0.1 Hz components in PI and SBP correlated with BRS. The increased variability in SBP during exercise could explain why the product of 0.1 Hz components in PI and SBP increased.

The different mechanisms of PI and SBP variability in the respiratory and 0.1 Hz frequency bands are important for the interpretation of changes in PI variability at 0.1 Hz during exercise. A study based on alpha blockade of 0.1 Hz oscillations in the circulation confirmed a previous theory that this oscillation in PI is almost entirely accounted for by a baroreflex mechanism, since it is not produced in the absence of a 0.1 Hz pressure oscillation (Cevese *et al.* 2001). Our results are in agreement with this hypothesis. During exercise, an increased variability of SBP might be a sign of increased sympathetic activity, and it explains a relatively high PI variability in some subjects at low BRS and high heart rate. The increased variability in PI at a decreased BRS in some of the subjects is the result of a response of the heart to the primary changes in SBP mediated by baroreflex. Blood pressure variability should therefore be taken into account for the evaluation of variability in PI. The PI variability alone does not express only the gain of autonomic reflexes; it is also conditioned by primary variability in blood pressure.

On the other hand, a causal interrelationship between the 0.1 Hz variability of SBP and PI, and BRS has been shown. During exercise, the increasing primary variability in SBP due to sympathetic activation was present. The number of subjects dropped in the low SBP-variability group and increased in groups with higher SBP-variability; a very high SBP-variability appeared during exercise. The increase in SBP variability did not change the relationship between the variability in pulse intervals and BRS. The variability of PI was related to both the actual value of BRS and the actual variability in SBP.

It is not easy to explain the interrelationship among circulatory changes during the recovery period. Whereas mean PI and its variability similarly as BRS reflect the normalization of nervous control of the sinus node, a contribution of local mechanisms on the blood

pressure decrease cannot be estimated in our measurements. It might be supposed that a balance between the effects of autonomic nerves on circulation is different from that at rest. A high variability of PI at high BRS could be a sign of increased parasympathetic activity and a concomitant sympathetic effect on the heart could explain seeming discrepancy between the mean PI and the PI variability. The relatively high SBP variability, which is BRS-independent and associated with a high variability in PI, support an assumption that sympathetic hyperactivity is still present.

In conclusion, the interrelationship between BRS and variability in circulation indicated that the variability of PI at a frequency of 0.1 Hz positively correlates with BRS and has a dampening effect on SBP variability at 0.1 Hz. Generally, an additional effect of primary variability of SBP on PI variability has been disclosed. During exercise, a relatively higher 0.1 Hz variability of SBP might be a sign of higher sympathetic vasomotor activity. The dampening effect of PI variability on variations in SBP is less effective in many subjects due to low BRS. The autonomic controlling response of subjects to exercise was not uniform. The determination of changes in the interrelationship between BRS and variability in SBP and PI might enable to evaluate the contribution of sympathetic vasomotor activity and baroreflex gain on heart rate variability.

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