Correlation between Spectral Measures of Systolic Blood Pressure Variability and Heart Rate Variability during Paced Breathing, Standing and Exercise

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Abstract

To provide insight on the somewhat controversial issue of the physiological correlates of spectral indexes of systolic pressure variability (SPV) we assessed the relations between them and those of heart rate variability (HRV) in 20 subjects during two sympathetic maneuvers, standing (S) and exercise (E). We also evaluated the percentage of statistical differences among 50-s epochs (PSDE) of the spectral measures dynamics obtained in 5-min steady-state conditions. From time-frequency spectra, high-frequency power of RR intervals (HF_{RR}), low-to-high-frequency ratio (LF_{RR}/HF_{RR}), low-frequency of systolic pressure (LF_{SP}), high-frequency of systolic pressure (HF_{SP}), high-frequency of respiration (HF_{Re}) and HF_{SP}-HF_{Re} time-frequency coherence were computed. LF_{SP}-lnHF_{RR}, LF_{SP}-RR and LF_{SP}-LF_{RR}/HF_{RR} correlations were -0.73±0.09, -0.77±0.06, and 0.66±0.13 respectively. During E, HF_{RR} decreased, HF_{SP} increased ($p<0.001$) and HF_{Re}-HF_{SP} coherence was 0.93±0.05. Global PSDE of the measures was 41±18%. HRV spectral measures show strong correlation with LF_{SP} power, novel evidence that supports its suitability as sympathetic index. The differential effect of E on HF_{RR} and HF_{SP} and high HF_{SP}-HF_{Re} coherence document the mechanical respiratory origin of HF_{SP}. Spectral measures of supposedly steady-state maneuvers present high PSDE.

1. Introduction

In clinical studies the low-frequency power of systolic pressure (LF_{SP}) is commonly used as an index of sympathetic vasomotor activity, because it is non-invasive, relatively simple to compute and capable of dynamically assessing the sympathetic vasomotor activity [1]. These characteristics make LF_{SP} an appealing indicator. However, evidences obtained from patients [2] and animals [3] indicate that its use as autonomic indicator is somewhat controversial. It is accepted that the high-frequency power of systolic pressure (HF_{SP}) depends on a mechanical respiratory effect [1], despite little evidence to support this concept.

It is likely that human autonomic cardiovascular function is mostly unsteady. This notion has great implications in the traditional spectral analysis of cardiovascular variability, because the usual practice is to apply methodologies that require the stationarity of RR intervals (RR) and systolic pressure (SP) series. Most of the times the stationarity of the series is presumed rather than tested [4]. When stationarity is tested, the researcher must face the difficult task of selecting a procedure from multiple approaches or contexts [5].

To provide insight on these issues, we assessed the relationships between the spectral indexes of systolic pressure variability (SPV) and of heart rate variability (HRV) during two sympathetic maneuvers and controlled breathing (CB). Additionally, we evaluated the percentage of statistical differences among epochs (PSDE) of the spectral measures dynamics obtained in steady-state maneuvers.

2. Methods

2.1. Subjects

Twenty healthy, normotensive and sedentary subjects, 13 men and 7 women, were studied. Mean age, height and weight were 23.4±1.6 years, 164±8 cm and 61.2±13 kg respectively. Their written informed consent was requested to participate.

2.2. Protocol

Volunteers visited the laboratory twice. The first time, their health status and anthropometric variables were evaluated, and in the second visit the experimental stage was carried out. The 5-min-long maneuvers employed to induce specific changes in the cardiac autonomic activity were: lying with spontaneous breathing (L), considered the control condition; postural change from lying to standing position (S), which elicits a sympathetic activity increase; lying with CB at 0.2 Hz with increased tidal volume of around 2.0 liters, and a single bout of 100W cycling exercise (E), which provokes substantial vagal withdrawal. Uniformity of the maneuvers performance was maintained as much as possible. Resting periods between maneuvers were 5 min long.

2.3. Recorded variables and signal acquisition

ECG was detected at the CM5 bipolar derivation using a bioelectric amplifier (Biopac Systems). Non-invasive blood pressure was measured by Finapres (Ohmeda). The respirogram was obtained by means of a stretching pneumograph (Nihon Kohden). ECG, blood pressure and respirogram signals were digitized at a sampling rate of 500 Hz via an acquisition and display system (Biopac Systems).

2.4. Data processing

R-wave peaks and SP values were detected to form the RR and SP time series which, together with respirogram, were cubic-spline interpolated, resampled at 4 Hz and detrended. Time-frequency spectra, estimated with the smoothed pseudo-Wigner-Ville distribution, were integrated in the standard low and high frequency bands to compute high-frequency power of RR (HF_{RR}), low-to-high-frequency ratio (LF_{RR}/HF_{RR}), LF_{SP}, HF_{SP} and high-frequency of respiration (HF_{Re}). Time-frequency coherence between HF_{SP} and HF_{Re} was obtained by cross-spectral analysis. Coherences greater than 0.5 were considered significant. The first minute of every maneuver was discarded because it included the transient changes produced by the onset of the maneuver. Indexes dynamics were ensemble-averaged for visualization purposes, and were segmented into 50-s epochs for statistical comparisons. PSDE was computed as the percentage of statistically significant differences ($p<0.05$) found in the intra-epochs comparisons of each spectral measure dynamics in relation to the total number of comparisons.

2.5. Statistical analysis

The values of the variables dynamics sampled at 50 s intervals were expressed as mean ± standard deviation (SD). Differences among these values during the maneuvers were tested by ANOVA for repeated measures. Post-hoc pairwise comparisons were performed by the Tukey test. Individual pooled mean values of the 50-s segments of the indexes dynamics throughout the different maneuvers were used to compute linear regression and correlation between SPV and HRV measures. Statistical significance was accepted at $p<0.05$.

3. Results

Table 1 presents the PSDE of the variables during the different maneuvers. Mean PSDE of all variables in all maneuvers was 41±18%, with a minimum of 14.9% for RR and a maximum of 60.4% for HF_{SP}, both in CB condition.

Table 1. Mean ± SD of the PSDE for each variable and maneuver. N=20

	L	S	E	CB
LF_{SP}	38.8±21.8	35.7±16	34.1±16	34.1±22.3
HF_{RR}	44.3±21.5	50.2±17	50.6±20	57.3±24.4
RR	17.6±17.3	43.9±27	58.0±23	14.9±16.4
$LF_{RR}HF_{RR}$	36.9±18.7	32.9±15	36.5±20	41.6±15.2
HF_{SP}	41.6±24	44.7±26	43.1±21	60.4±14

Ensemble averages of the variables dynamics and their mean values sampled each 50 s are depicted in Figure 1. RR (Fig. 1A) and $\ln HF_{RR}$ power (Fig. 1B) decreased progressively, with respect to L, during S and E conditions ($p<0.001$ for all segments), while LF_{RR}/HF_{RR} ratio (Fig. 1C) and LF_{SP} (Fig. 1D) increased progressively ($p<0.001$).

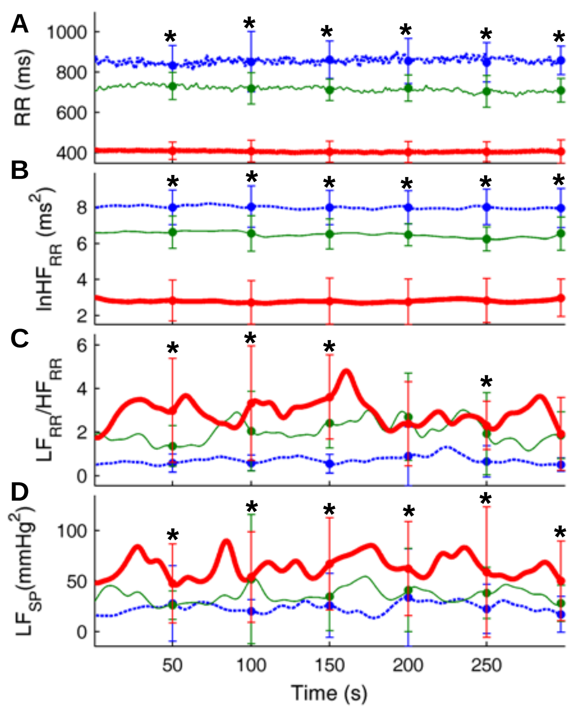

Figure 1. Ensemble averages and mean±SD values at 50s of the variables dynamics during L (dotted line), S (thin line) and E (thick line) maneuvers. (A) RR, (B) $\ln HF_{RR}$, (C) LF_{RR}/HF_{RR} ratio and (D) LF_{SP} power.
* $p<0.01$ between maneuvers.

For each subject, linear correlations and regressions between SPV and HRV indexes were computed using the pooled mean of each variable dynamics epoch (Fig.2).

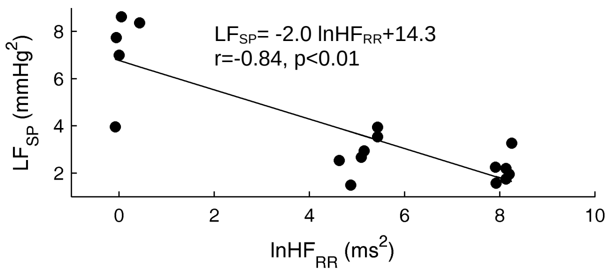

Figure 2. Representative example of an individual relation between LF_{SP} and a HRV index and the respective regression.

Mean individual correlations of LF_{SP}-RR, LF_{SP}-lnHF_{RR} and LF_{SP}-LF_{RR}/HF_{RR} relations were -0.77±0.06, -0.73±0.09, and 0.66±0.13 respectively. Individual and mean linear regressions are shown in Figure 3. Intersubject dispersion of the regressions was large.

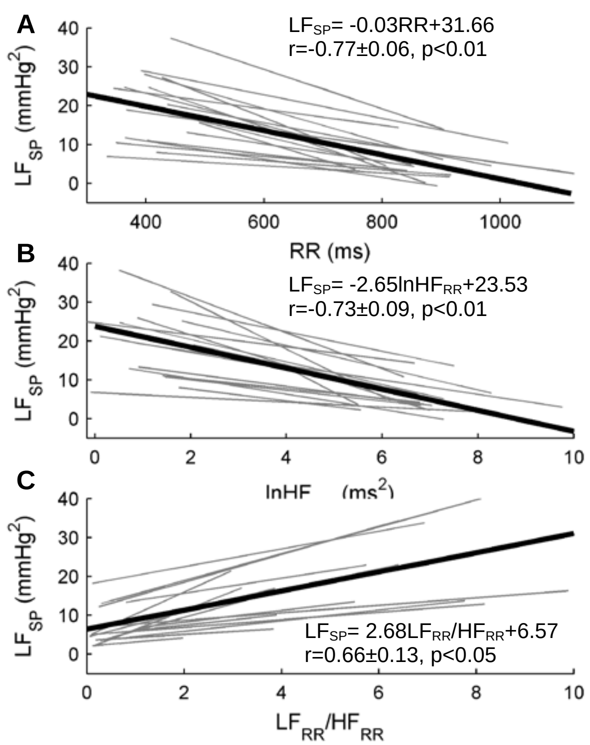

Figure 3. Mean linear regression computed from the individual regressions between LF_{SP} power and (A) RR, (B) HF_{RR} power and (C) LF_{RR}/HF_{RR} ratio.

In relation to L and for the six values per variable dynamics, lnHF_{RR} power increased ($p<0.001$) in CB and decreased drastically in E maneuver ($p<0.001$). HF_{SP} power dynamics increased ($p<0.001$) in both CB and E conditions (Fig. 4).

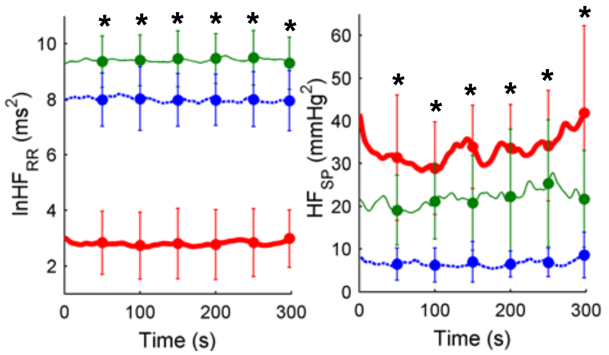

Figure 4. Ensemble averages and mean±SD values at 50s of the (A)lnHF_{RR} and (B)HF_{SP} power dynamics during L (dotted line), E (thick solid line) and CB (thin solid line) conditions. *p<0.001 between maneuvers.

Figure 5 depicts the ensemble averages of HF_{SP}-HF_{Re} time-frequency coherence obtained during CB and E. The pooled averages of the individual time-frequency coherence between HF_{SP} and HF_{Re} power in CB and E were 0.96±0.07 and 0.93±0.05 respectively.

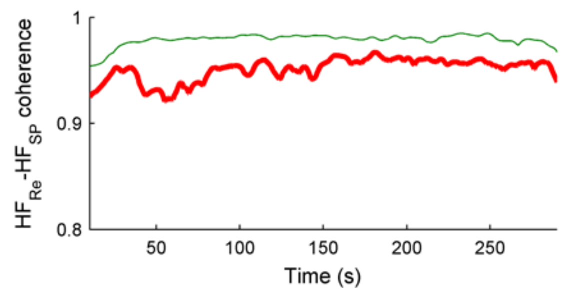

Figure 5. Ensemble averages of HF_{SP}-HF_{Re} time-frequency coherence during CB (thin line) and E (thick line).

4. Discussion and conclusions

Our main findings are: 1) High PSDE are found for all spectral measures dynamics in the four supposedly steady-state conditions. 2) As indicated by HF_{RR}, mean heart period and LF_{RR}/HF_{RR}, S and E maneuvers induce different levels of sympathetic activation with respect to L. 3) These HRV indexes show strong correlation with LF_{SP} power, providing evidence that supports its suitability as a sympathetic index. 4) That HF_{RR} and HF_{SP} change in opposite directions during E and the strong coherence between HF_{Re} and HF_{SP} support the mechanical respiratory origin of HF_{SP}.

Dynamic exercise at 100 W produces greater sympathetic activation and vagal withdrawal than active postural change, as indicated by the changes in LF_{RR}/HF_{RR}, heart rate and lnHF_{RR} power (Fig. 1), observations that corroborate previous findings [6].

Reported evidence supporting the usage of LF_{SP} power as vasomotor sympathetic indicator is sometimes controversial. Studies performed in patients [2] or in animals [3] conclude that LF_{SP} power does not appear to be suitable as quantitative index of sympathetic activity and that it has poor correlation with other measures of autonomic function. Previous studies that provide evidence in favor of LF_{SP} power as indicator of sympathetic activity have been performed mostly in animals [7,8,9]. There are only a few human studies with this aim, either with patients [10] or healthy subjects. It has been reported that LF_{SP} power increased during 90° upright tilt in both healthy [8] and hypertensive subjects [11], and that it increases during moderate dynamic exercise [12]. To the best of our knowledge, this is the first study to document in healthy subjects that during different levels of sympathetic drive, LF_{SP} power and HRV spectral measures present strong correlation (Fig. 3), extending the reported evidence in favor of the good performance of LF_{SP} power as a sympathetic marker

Although further studies are required, our findings suggest that LF_{SP} power could be a suitable complement to: 1) LF_{RR} power, an ambiguous measure that depends on both the sympathetic and the vagal activity [1] and whose amplitude decreases dramatically during exercise [12], drawbacks not presented by LF_{SP} power. 2) Muscle sympathetic nerve activity, invasive and technically difficult to measure, characteristics that make it little used in clinical studies.

Few studies seek the functional correlates of HF_{SP} power. It has been reported that HF_{SP} power is a mechanical consequence of respiration [8] and also that during exercise HF_{SP} power is mainly due to the mechanical effect of hyperpnea [12]. CB with high tidal volume increases the HF_{RR} power, effect analogous to vagal stimulation, and also HF_{SP} power. In our study, E produces great decrease of HF_{RR} power due to vagal withdrawal and increase of HF_{SP} power (Fig. 4), which presents strong coherence with respiration (Fig. 5). These findings indicate the respiratory origin of HF_{SP} power, mediated mainly through a non-neural mechanism, without discarding a minor influence of the variability of cardiac output.

The high PSDE values found during supposedly steady-state maneuvers (Table 1) bear implications for the statistical handling of the results. Furthermore, the common and erroneous practice of applying spectral analysis techniques that require stationarity [4] to analyze non-stationary signals is avoided when a time-frequency distribution is systematically applied to perform the spectral analysis of any cardiovascular variable and in any condition.

In conclusion, as indicated by HRV spectral measures, S and E maneuvers induce different levels of sympathetic activation. These indexes show strong correlation with LF_{SP} power, providing evidence that supports its suitability as a sympathetic index. The differential effect of E, increasing HF_{SP} and decreasing HF_{RR}, and the significant coherence between HF_{SP} and HF_{Re} document the mechanical respiratory origin of HF_{SP}. Spectral measures of supposedly stationary recordings present high PSDE, established with a time-frequency distribution, technique that should be systematically used for the spectral estimation of cardiovascular series, regardless the stationarity, or lack thereof, of the signals.

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