Time Courses of Central Frequencies of Low Frequency Components of Systolic and Diastolic Pressures and RR Intervals Variabilities in Response to Incremental Isometric Exercise

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Abstract

To test the sympathetic activity estimating capability of central frequencies of low frequency (CFLF) components of systolic pressure (pLFSP), diastolic pressure (pLFDP) and R-R intervals (CFLRIRP), in 31 healthy subjects performing continuously increasing legs muscle force until fatigue, we assessed: the instantaneous time courses of CFLFSP, CFLDFP, CFLIRP, their respective low frequency powers (pLF), estimated by a time-frequency distribution, CFLF-pLF correlations and the comparisons between CFLF. Based on the threshold effect they showed, the time courses of all measures were divided into before (BTP) and after (ATP) threshold periods. Time courses of CFLFSP, CFLDFP and CFLIRP showed: 1. similar patterned responses of gradual increment in BTP, abrupt decrease in ATP and fast increment in the initial recovery period (IRP), inverse to the pattern presented by pLF dynamics; 2. 20-s epoch means (EM) differences (p<0.04) between them in control and BTP according to the inequality CFIRP > CFLFSP ≥ CFLFDP, that disappeared in ATP and IRP. CFLF-pLF correlations (p<0.01) of the three variables were negative and greater (p<0.01) in ATP than BTP and IRP. Our findings support that CFLF can be used as sympathetic activity measures with some specificity: CFLFIRP for the cardiac sympathetic outflow and CFLFDP for the vasomotor one.

1. Introduction

In the corpus of basic knowledge on HRV established by consensus, only the powers of the low (pLF) and high frequency components were considered reliable autonomic activity indexes [1]. pLF of cardiovascular variability (CVV) spectra have been successfully used as noninvasive estimators of sympathetic activity, the one corresponding to systolic pressure (pLFSP) showing better consistency than that of R-R intervals series (pLFRIRP) [2].

In a previous study we reported, under conditions of continuously increasing muscle force (CIMF) by performing handgrip and one leg extension, the significant correlation between the time courses of pLFSP, pLF of diastolic pressure (pLFDP) and pLFRIRP, as well as their similar detection of the onset of the abrupt increase of sympathetic activity, triggered by the activation of metaboreflex, threshold effect that allows dividing the sympathetic response into before threshold period (BTP) and after threshold period (ATP) [3].

Few reports have documented that maneuvers that increase sympathetic activity, such as the active orthostatic test [4] and dynamic exercise [5], provoke a leftward shift of the central frequency of pLFRIRP. However, the effects of sympathoexcitatory conditions on either the central frequencies of pLFSP (CFLFSP) and of pLFDP (CFLDFP), or on the relation between pLF and their central frequencies (CFLF), have not been reported. Moreover, it is still unknown whether the baseline values of CFLFSP, CFLDFP and CFLIRP are similar or not.

To provide evidence of the CFLF capability to estimate the sympathetic outflow arriving at the heart or the vessels, we assessed, in healthy subjects performing two-legs CIMF, the differences between the instantaneous time courses of CFLFSP, CFLDFP and CFLIRP, as well as their relationship with pLFSP, pLFDP and pLFRIRP, computed by a time-frequency distribution.

2. Methods

2.1. Subjects

Thirty one healthy, nonsmoking and sedentary subjects, 24 men and 7 women, participated. Their age, height and weight were 22.1±2.7 years, 167.6±7.9 cm and 66.8±11.3 kg respectively. Their written informed consent was requested to participate. This study was approved by the ethics committee of our university.

2.2. Protocol

In a first visit to the laboratory, the health status of the subjects was evaluated and they were trained to correctly execute the isometric exercise. In a second visit, the
experimental procedure was carried on. Each session consisted on three successive stages: 1 min of control; subject performing CIMF in sitting position, following a target linear pattern visually presented, by isometrically extending both legs at a rate of 0.2 kg.s⁻¹ until exhaustion, where the maximal force was attained; and recovery for 2 min. ECG, arterial pressure (AP) and muscle force (MF) were recorded throughout the entire session.

2.3. Signal recording and acquisition

ECG was detected at the thoracic bipolar lead CM5 using a bioelectric amplifier (Biopac Systems). AP was recorded by Finapres (Ohmeda). MF was measured with a dynamometer (Stoelting) mechanically adapted to a chair. All signals were digitized at a sampling rate of 1 kHz via an acquisition and display system (Biopac Systems).

2.4. Data processing

Fiducial points of ECG and AP recordings were detected to construct the RR, systolic pressure (SP) and diastolic pressure (DP) time series, which were cubic-spline interpolated, resampled at 4 Hz and detrended. Time-frequency spectra of the series were estimated with the smoothed pseudo-Wigner-Ville distribution and integrated in the standard low-frequency band of HRV (Fig. 2A). Statistical significance was set at p<0.05.

2.5. Statistical analysis

Data are expressed as mean±SD. 20-s epoch means (EM) of the measures time courses were computed. Inter- and intra-measures EM comparisons in control, BTP, ATP and recovery were performed by ANOVA for repeated measures. Individual linear correlations between LF and pLF dynamics in BTP, ATP and recovery were obtained. Statistical significance was set at p<0.05.
Ensemble averages of the CTFSP, CTFDP and CTFRR vs. %MFMAX relations showed similar patterned responses of gradual increment of CTFSP and CTFDP, more subtle in CTFRR, in BTP, and abrupt decrease in ATP (Fig.4), inverse to the pattern presented by pLF dynamics, roughly in BTP but notably in ATP (Fig. 3). Mean thresholds detected by CTFSP, CTFDP and CTFRR of 79±9, 80±9 and 78±9 %MFMAX respectively, were similar. Thresholds detected by pLF and CTF were not different (Fig. 3-4).

Ensemble averages of the time courses of CTFSP, CTFDP and CTFRR showed: a fall at the onset of CIMF with respect to control, the smallest corresponding to CTFRR; gradual increment in BTP, except for CTFRR, followed by an abrupt fall until the end of CIMF (ATP), that coincides with the start and peak of pLF dynamics surge; and a fast increment of the three CTF in the first 40s of IRP, where CTFRR showed the greatest range of change (Fig. 5). EM inter comparison of CTFSP, CTFDP and CTFRR on each period showed: differences (p<0.04) in control period according to the inequality CTFRR (98±10 mHz)>CTFSP (91±12 mHz)>CTFDP (86±8 mHz) that remained in the initial part of BTP; in the middle and end of BTP, CTFSP was similar to CTFDP but both were different (p<0.01) to CTFRR; EM of the three CTF were similar in ATP and IRP, but in the end recovery period (ERP), EM of CTFSP and CTFDP remained similar and were again different to CTFRR (p<0.01, Fig. 5). While EM of CTFRR were different (p<0.03) to control during BTP, ATP and IRP, those of CTFDP and CTFSP were only different (p<0.03) in ATP.

4. Discussion

The dynamics of sympathetic activity changes are assessed by the low frequency components of CVV in the main dimensions of spectral analysis, power and central frequency over time, as supported by the finding that the instantaneous time courses of CTFSP, CTFDP and CTFRR show: 1) similar patterned responses of gradual increment in BTP and abrupt decrease in ATP followed by a rapid increase in IRP (Fig.5), roughly inverse to the pattern presented by pLF dynamics in BTP but noticeably so in
ATP and IRP (Fig. 3); 2) inter-measures differences in control and BTP according to the inequality: $C_{LF_{RR}}>C_{LF_{SP}}>C_{LF_{DP}}$, that disappear in ATP and IRP but return to control values in ERP (Fig. 5); and 3) negative correlations with their corresponding $p_{LF}$, greater in ATP and IRP than BTP (Table 1).

The combination of linear CIMF, continuous response measurement and time-frequency analysis allows assessing the degree of stimulus-response proportionality, providing greater robustness to the evidence. This situation contrasts with the leftward shift of $C_{LF_{RR}}$ documented by a single mean value in other studies [4,5].

A possible explanation for the differences found in control period between the magnitudes of the three $C_{LF}$ dynamics is that the sympathetic autonomic nuclei that innervate the heart modulate RR series at a greater frequency (centered around 98 mHz) than the ones that innervate the vessels, modulating DP series (about 86 mHz). Thus, cardiac and vasomotor sympathetic branches not only show a different anatomic distribution but operate at different modulating frequencies. The intermediate frequency of SP series would result from the influence of both modulatory branches, with some prevalence of the vasomotor one. During BTP, with the reduction of the vasomotor sympathetic activity the differences between $C_{LF_{SP}}$ and $C_{LF_{DP}}$ disappear, but they remain different from $C_{LF_{RR}}$, fact that further supports the functional differences between sympathetic branches. In ATP, the abrupt activity increase of both sympathetic branches makes the three $C_{LF}$ to become similar, effect that remains until IRP (Fig. 5). In ERP, $C_{LF_{RR}}$ is again greater than $C_{LF_{SP}}$ and $C_{LF_{DP}}$. Another possible contributing effect to the $C_{LF}$ change is the resonance of the feedback loop of AP that has been documented by the autoregressive modeling of the leftward shift of $C_{LF_{RR}}$ under tilt condition [6].

The negative correlations found between $C_{LF}$ and $p_{LF}$ (Table 1) show another case of the inverse relations between the amplitude and frequency of the same signal that is added to those already known to physiologists, such as the ones of electroencephalographic rhythms and respiratory sinus arrhythmia, with the peculiarity that the leftward shift of $C_{LF}$ with growing $p_{LF}$ indicates sympathoexcitation, as it occurred in ATP, and the rightward $C_{LF}$ shift with reduced $p_{LF}$ marks sympathoinhibition, as in BTP and recovery. The sympathoexcitatory effect provoked by CIMF in ATP, marked by the leftward shift of $C_{LF_{RR}}$, agrees with the reports of previous studies in other sympathetic maneuvers [4-6]. Additionally, $C_{LF_{RR}}$ has been proposed as a good feature to discriminate autonomic impairment in diabetic patients from normals [7] and newborn seizures from non-seizures [8].

To the best of our knowledge, this is the first study to report that $C_{LF}$ show significant correlations with $p_{LF}$ that improve in ATP, correctly indicate the threshold of metaboreflex triggering and present different baselines that are modified by CIMF, supporting their possible use as sympathetic activity measures, with some specificity: $C_{LF_{RR}}$ marks cardiac sympathetic activity and $C_{LF_{DP}}$ the vasomotor one, although further studies are required to confirm these notions.

In conclusion, the significant and characteristic changes elicited by CIMF in $C_{LF_{SP}}$, $C_{LF_{DP}}$ and $C_{LF_{RR}}$ correctly indicate, but inversely, the known responses of reduction and abrupt increment of sympathetic activity before and after metaboreflex triggering. $C_{LF}$-$p_{LF}$ association grows with sympathoactivation, as shown by the greater correlations found in ATP. The different $C_{LF}$ levels and their changes found suggest that the cardiac modulatory sympathetic effect presents greater operating frequency than the vasomotor one. These findings suggest that $C_{LF_{SP}}$, $C_{LF_{DP}}$ and $C_{LF_{RR}}$ can be trustable vasomotor or cardiac sympathetic outflow indicators that complement and strengthen the performance of the usual autonomic activity spectral measures.

References


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