Comparison of the time-frequency structure of pulse rate and heart rate variability during non-stationary conditions

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INTRODUCTION

In stationary conditions, the pulse rate variability (PRV) estimated from the photoplethysmography signal (PPG) was recently proposed as alternative measurement of the heart rate variability (HRV) [1]. Here, time-frequency (TF) and TF coherence analysis were used to compare the time-varying spectral properties of both signals during tilt table test, in order to assess whether PRV can be used as a surrogate of HRV in the analysis of the autonomic modulation of heart rate in non stationary conditions.

MATERIAL AND METHODS

Seventeen volunteers (mean age 28.5±2.8 years, 11 males) without any previous cardiovascular history underwent a tilt table test which consisted of three phases: 4 min in early supine position (T1), 5 min in 70^o head-up position (T2) and 4 min in later supine position (T3). Beats from ECG and pulses from PPG were automatically detected and evenly resampled at 4 Hz to generate heart and pulse rates. Abnormalities and artifacts in the heart and pulse rates were subsequently corrected. The smoothed pseudo Wigner-Ville distribution (SPWVD), $S(t,f)$, [2] was then used to estimate (i) the temporal evolution of the power content within low frequency ([0.04, 0.15 Hz], LF) and high frequency ([0.15, 0.4 Hz], HF) bands; (ii) the temporal patterns of spectral coherence in LF and HF bands by means of quadratic TF coherence $\gamma(t,f)$ [3]. The Wigner-Ville distribution was filtered in both time and frequency using the separable elliptical exponential kernel proposed in [3]. The degree of TF filtering, which gave a frequency resolution of 0.0313 Hz and a time resolution of 15 s, was sufficient to provide a consistent estimation of $\gamma(t,f)$ (i.e. bounded in [0, 1]), for all subjects. Instantaneous LF and HF powers $P_{x,B}(t)$, with $x=\{HRV,PRV\}$, $B=\{LF,HF\}$, as well as band coherences $\gamma_B(t)$ were estimated by averaging $S_x(t,f)$ and $\gamma(t,f)$ in the LF and HF bands. Physiological analysis was then performed on both HRV and PRV. We assessed the statistical significance of the changes observed in $P_{LF}(t)$ and $P_{HF}(t)$ during time, by iteratively comparing $P_{x,B}(t)$ with baseline values, by means of the Student's t-test. Baseline values were estimated by averaging $P_{x,B}(t)$ in an interval which ranged from 15 to 45 s (begin of T1).

RESULTS AND DISCUSSION

The results of TF and TF coherence analysis for a subject (male, 30 years old) are reported in fig. 1. Heart and pulse rates are reported in panel (a). The SPWVD of HRV and PRV are shown in panels (b)-(c). The temporal evolution of the instantaneous power within the LF and HF bands, $P_{x,B}(t)$, with $x=\{HRV,PRV\}$, $B=\{LF,HF\}$, are reported in panel (d). Note that, as also shown in panels (b)-(c), the spectral properties of the HRV and PRV signals did follow the same temporal patterns. The main difference lies in the slight increase of $P_{PRV,HF}(t)$ with respect to $P_{HRV,HF}(t)$. This bias increased in T2. Results of TF coherence analysis are reported in panels (e)-(f). The quadratic TF coherence $\gamma(t,f)$ shows that during T1 and T3, HRV and PRV presented an almost perfect correlation for all frequencies. During T2, $\gamma(t,f)$ decreased in HF band while around 320 s, $\gamma(t,f)$ also decreased in LF band due to artifacts in the PPG signal (marked as crosses). Finally, the temporal evolution of band coherences $\gamma_B(t)$, confirms the previous observations: HRV and PRV were highly linearly coupled, at least in LF band . Note that these results refer to the subject which presented the lowest $\gamma_{HF}(t)$. Global results, obtained by averaging $P_{x,B}(t)$ and $\gamma_B(t)$ among subjects, are reported in fig.2(a)-2(b), respectively. Averaged $P_{HRV,B}(t)$ and $P_{PRV,B}(t)$ presented the same temporal patterns and $P_{PRV,B}(t)$ is slightly higher than $P_{HRV,B}(t)$, being $P_{PRV,B}(t)-P_{HRV,B}(t)<10^{-3}$ s^{-2}. Inspection of fig. 2(a) reveals the transient nature of the autonomic response to the orthostatic stress: $P_{LF}(t)$ increased immediately after head–up tilt (T2) and rapidly came back to baseline values when the supine position was restored (T3). The statistical analysis showed that the increase of $P_{LF}(t)$ became statistically significant ($p<0.05$) with respect to baseline values about two minutes after the begin of T2. The power content in HF band did not present any statistically significant change. It is worth noting that there was agreement between the physiological analysis based on HRV and PRV analysis.

Band coherences $\gamma_B(t)$ showed that despite of the changes observed in fig. 2(a), the degree of linear coupling between HRV and PRV was constant during time, and no relevant variations were observed even during upward and downward tilting. During the entire procedure, $\gamma_{LF}(t)$ fluctuated around 0.97±0.04, while $\gamma_{HF}(t)$ fluctuated around 0.92±0.06 during supine positions (T1 and T3) and slightly decreased in T2 (0.87±0.10). The differences observed in HF are likely due to the effect of the variability of the pulse transit time signal (PTT), i.e. the beat–to–beat changes in pulse wave velocity [4], and further studies on this matter are needed. In this work we observed that during tilt table test, HRV and PRV had (i) TF indices with similar temporal patterns and (ii) steadily high quadratic TF coherence; (iii) HRV and PRV analysis provided the same results about the effect of the orthostatic stress on the autonomic modulation of heart rate. Our results indicate that PTT variability introduces some small differences in the TF structure of HRV and PRV, mainly in HF band. These differences were sufficiently small to suggest the use of the PRV signal as a surrogate of HRV signal in non–stationary conditions, at least during tilt table test.

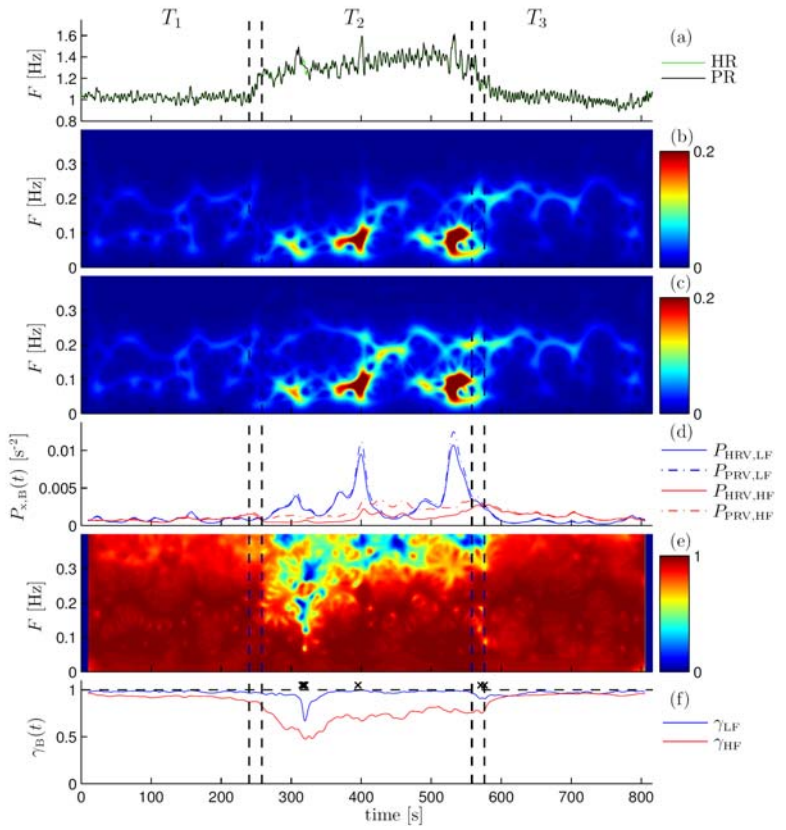

Fig. 1: (a) Herat and pulse rate; (b) SPWVD of HRV, $S_{HRV}(t,f)$; (c) SPWVD of PRV, $S_{PRV}(t,f)$; (d) Instantaneous power, $P_{x,B}(t)$; (e) TF coherence $\gamma(t,f)$; (f) Band-coherences $\gamma_B(t)$. Crosses mark artifacts

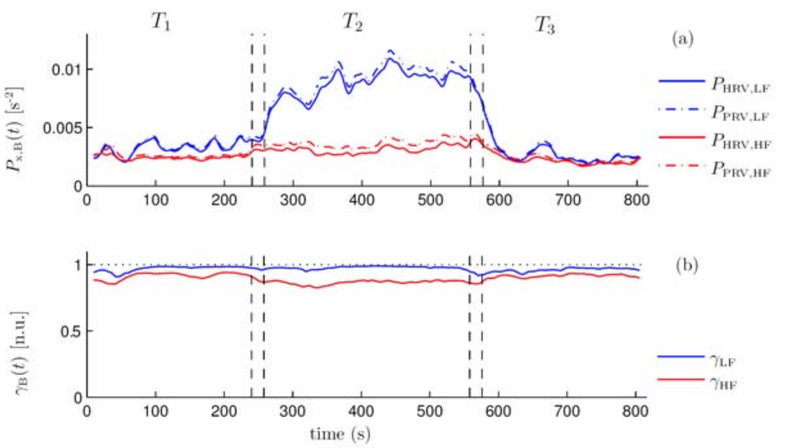

Fig. 1: (a) Instantaneous powers averaged among subjects; (b) Band-coherences averaged among subjects

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