Respiration-Guided Analysis of Pulse and Heart Rate Variabilities for Acute Emotional Stress Assessment

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Abstract

Acute Emotional Stress may be assessed through the changes on the autonomic nervous system. Pulse Rate Variability (PRV) and Heart Rate Variability (HRV) are well known and widely used as markers of autonomic nervous system. Pulse photoplethysmographic and electro-cardiographic signals were synchronously recorded during relax and stress stages from 80 young healthy students during an ad hoc experiment. To evaluate the agreement among HRV and PRV, frequency indices were computed over 1-min-length running window on the classical spectral bands [LF:0.04-0.15Hz, HF:0.15-0.4Hz], extended HF band [0.15Hz-half mean Heart Rate], HF band centered at respiratory frequency with a bandwidth of 0.1 Hz. Between relax and highest stress stage most of the HRV indices show significant changes but most of the PRV indices do not. Most of the indices showed significant differences between PRV and HRV on relax stages. In contrasts, during stress stages they do not show significant differences. These results suggest that pulse arrival time variability is higher during relax.

1. Introduction

As response of a stress stimulus the autonomic nervous system generates an inhibition of the parasympathetic nervous system and an activation of the sympathetic nervous system [1].

Both systems act in the opposite way generating activity in the adrenal medulla that is reflected in the increase of the heart rate, the blood pressure, the bronchodilation, the sweating, the metabolic activity and the concentration of glucose in the blood[2].

Pulse Rate Variability (PRV) and Heart Rate Variability (HRV) are widely used tools for non-invasive autonomic nervous system assessment. Although some differences in indices extracted from HRV and PRV exist, PRV could be used as a surrogate of HRV during the tilt table test[3].

The ES3 Project [4], attempting to develop a continuously and a non-invasively measurement of acute emotional stress in young people, in relation to assess stress has analyzed HRV and respiratory frequency pointing out the importance of taking into account respiratory information in HRV analysis [5].

Due to the fact that HRV and PRV may provide different but complementary information, this paper presents a reliability comparison between HRV and PRV including respiratory frequency information for acute emotional stress assessment.

2. Materials and Methods

2.1. Database

Respiratory signal, pulse photoplethysmographic (PPG) and electrocardiographic (ECG) signals were synchronously recorded during relax and different stress states from 80 young healthy students at Autonomous University of Barcelona (Spain) and University of Zaragoza (Spain). PPG and respiratory signal were sampled at 250Hz and ECG was sampled at 1kHz by using ABP-10 module of the Medicom device (Medicom MTD Ltd.). Relax and stress states were achieved by using the experimental protocol described in [5]. The following stages of the protocol were analyzed: prerelaxing stage before relax (PRB), deep relax (R), prerelaxing stage before stress (PSB), story

telling stage (ST), where subjects were listening to stories that they had to remember, stress anticipation (SA), where subjects were waiting for their evaluation, and video exposition stage (V), where a video showing the subject's performance was displayed in front of an audience. Other stages of the experimental protocol were excluded because they required the subject to speak.

2.2. Respiratory frequency estimation

Based on respiratory frequency estimation described in [5], the respiratory signal was filtered with a pass-band filter (cutoff frequencies of 0.03Hz and 0.9Hz) and downsampled from 250Hz to 4 Hz. For each stage respiratory frequency ($F_R(k)$) was estimated on 1-min-length windows as position of the maximum of the power spectrum density ($S_k(f)$) of the respiratory signal. $F_R(k)$ was considered only if the peakness (P_k) of $S_k(f)$ is higher than 65%. P_k was defined as:

$$P_k = \frac{\int_{F_R(k)-0.1}^{F_R(k)+0.1} S_k(f)df}{\int_{0.08}^{0.8} S_k(f)df} \cdot 100 \qquad (1)$$

2.3. Electrocardiography

Heart beats were detected from the ECG signal using an algorithm based on the discrete wavelet transform [6]. In addition, an instantaneous Heart rate signal (HR) was obtained from the beat occurrence time series using an algorithm based on the integral pulse frequency modulation model, which takes into account the presence of ectopic beats [7].

2.4. Pulse photoplethysmography

PPG signal was filtered using a low pass FIR filter with a cut-off frequency of 35 Hz (order 50). Then a high pass FIR filter with a cut-off frequency of 0.3 Hz (order 5000) was applied to the signal. PPG artifacts were suppressed through a Hjorth-parameter-based PPG artifact detector described in [8]. Pulses were detected from the PPG signal on those time slots without artifacts by an algorithm based on [9]. Finally, an instantaneous Pulse rate signal (PR) was obtained using an algorithm based on the integral pulse frequency modulation model, as with the HR signal [7].

2.5. Pulse and heart rate variabilities indices

The following PRV and HRV frequency indices were computed over the same 1-min-length running window from synchronous PR signal and HR signal: Power on Low frequency (P_{LF}) and High frequency (P_{HF}) classical spectral bands [LF:0.04-0.15Hz, HF:0.15-0.4Hz]. Power in extended high frequency (HF) band (P_{HFex}) [0.15Hz-half mean Heart Rate]. Power in HF band centered at respiratory frequency (P_{HFr}) [$F_R(k)$-0.05, $F_R(k)$+0.05Hz]. P_{LF} and P_{HF} normalized by the sum of P_{LF} and P_{HF} (P_{LFn} and P_{HFn}). P_{LF} and P_{HFex} normalized by the sum of P_{LF} and P_{HFex} (P_{LFexn} and P_{HFexn}). P_{LF} and P_{HFr} normalized by the sum of P_{LF} and P_{HFr} (P_{LFm} and P_{HFm}). Ratio between P_{LF} and P_{HF} (LF/HF). Ratio between P_{LF} and P_{HFex} ($LF/HFex$). Ratio between P_{LF} and P_{HFr} (LF/HFr). Every time window where $F_R(k)$ falls within the LF band were excluded as in [5].

Indices from PRV were compared with those from HRV using differences of least squares means (DLSM) of fixed effects from linear mixed models with the subject as a random effect. For Non-Normal distributed indices the Box-Cox were used.

3. Results

Percentage change between prerelaxing stage before relax (PRB) and prerelaxing stage before stress (PRS) for HRV and PRV indices are show in Table 1. HRV and PRV indices related to HF band centered at F_R and related to HF extended band are not significantly different between PRB and PRS, except for P_{HFex} and P_{HFexn} in HRV. For classic band only P_{LF} is not different between PRB and PRS.

Table 1. Percentage change between prerelaxing stage before relax (PRB) and prerelaxing stage before stress (PRS) for HRV and PRV indices. Values in [%] *p-value < 0.05

| | PRB vs PRS | |
	HRV	PRV
P_{HF}	-14.43*	-12.61*
P_{HFr}	-6.60	-4.84
P_{HFex}	-10.77*	-9.11
P_{HFn}	-4.34*	-4.00*
P_{HFrn}	-2.26	-1.78
P_{HFexn}	-3.72*	-3.36
LF/HF	14.90*	13.75*
LF/HFr	8.82	7.53
$LF/HFex$	12.08	10.97
P_{LF}	3.01	3.22
P_{LFn}	3.37*	3.10*
P_{LFm}	1.76	1.35
P_{LFexn}	3.32	2.94

Table 2 shows percentage change between Relax (R)

Table 2. Percentage change between Relax (R) and each stage for each HRV and PRV indices. Values in [%]
p-value < 0.05

	PRB vs R		PRS vs R		SA vs R		ST vs R		V vs R	
	HRV	PRV	HRV	PRV	HRV	PRV	HRV	PRV	HRV	PRV
P_{HF}	10.39*	9.27*	21.69*	19.43*	3.34	-8.39	13.49	0.22	14.20*	-2.16
P_{HFr}	19.04*	16.34*	24.06*	20.24*	-0.81	-14.24*	5.19	-9.32	11.37	-7.84
P_{HFex}	12.30*	11.13*	20.82*	18.55*	7.88	-3.26	23.54*	13.39	19.88*	6.06
P_{HFn}	2.44	2.10	6.49*	5.86*	-0.12	-2.81	-8.05*	-10.96*	7.24*	3.99
P_{HFrn}	4.73*	4.24*	6.84*	5.92*	-1.57	-4.41*	-9.98*	-12.73*	5.55*	2.09
P_{HFexn}	2.90*	2.53	6.38*	5.70*	1.22	-1.39	-4.70	-7.01*	9.14*	6.16*
LF/HF	-11.58	-9.44	-31.13*	-26.88*	-0.27	9.80	24.41*	31.64*	-41.59*	-23.17*
LF/HFr	-23.50*	-18.66*	-35.46*	-28.33*	3.8	14.36*	31.12*	37.69*	-37.19*	-16.75
$LF/HFex$	-14.03*	-11.74	-29.71*	-25.51*	-5.09	5.44	14.63	21.38*	-51.51*	-33.80*
P_{LF}	0.12	0.79	-2.98	-2.52	2.20	1.34	34.01*	31.17*	-22.46*	-26.79*
P_{LFn}	-2.06	-1.81	-5.63*	-5.08*	0.21	2.34	5.81*	7.80*	-6.13*	-3.25
P_{LFrn}	-3.8*	-3.51*	-5.66*	-4.92*	1.38	3.48*	6.81*	8.58*	-4.15*	-1.39
P_{LFexn}	-3.19*	-2.86	-6.73*	-5.98*	-0.90	1.72	4.28	6.32*	-9.88*	-6.51*

Table 3. Relative error between HRV and PRV indices, and mean Respiration frequency for each stage. Values in [%]
*p-value < 0.05

	PRB	PRS	R	SA	ST	V
P_{HF}	-24.56*	-22.58*	-26.11*	-12.47*	-9.34	-5.92
P_{HFr}	-28.61*	-26.49*	-32.91*	-17.29*	-15.27	-9.24
P_{HFex}	-21.07*	-19.26*	-22.68*	-9.44	-8.31	-4.63
P_{HFn}	-4.54*	-4.20*	-4.90*	-2.16	-2.15	-1.36
P_{HFrn}	-5.17*	-4.68*	-5.71*	-2.84	-3.13	-1.97
P_{HFexn}	-3.79*	-3.44*	-4.19*	-1.50	-1.95	-0.88
LF/HF	15.45*	14.30*	17.07*	7.81	8.30	4.65
LF/HFr	18.10*	16.95*	21.31*	11.62	13.02	7.54
$LF/HFex$	13.00*	11.91*	14.75*	5.27	7.43	3.47
P_{LF}	-5.29	-5.06	-4.58	-3.67	-0.26	-1.00
P_{LFn}	3.52*	3.25*	3.75*	1.65	1.67	1.07
P_{LFrn}	3.84*	3.43*	4.11*	2.02	2.25	1.50
P_{LFexn}	3.60*	3.22*	3.91*	1.35	1.81	0.86
$F_{R}(k)$	0.26	0.26	0.27	0.30	0.34	0.33

and others stages for each HRV and PRV indices. Particularly for SA stage, only PRV indices related to HF band centered at $F_R(k)$ are able to distinguish SA from R stage. Discrimination capability among PRB, PRS, ST stages and R are equivalent between HRV and PRV indices. Most of the HRV indices on V stage are significant different to HRV indices on R. In contrasts, just few PRV indices on V stage are significant different to PRV indices on R.

Relative error between HRV and PRV indices for each stage is shown in Table 3. Besides P_{HF} and P_{HFr}, all HRV and PRV indices on SA, ST and V are similar. Only P_{LF}, among others HRV and PRV indices, is not different on PRB, PRS and R stages.

4.   Discussion and conclusions

Significant differences between PRB and PRS are not expected due to the experimental design and in order to use R stage as reference. However, they were observed for classic HF band indices and indices related to HF extended band and therefore, these indices should not be used to estimate stress levels. May be these indices are an overestimation of sympathetic activity and an underestimation of parasympathetic activity as is suggested in [5].

The PLF values from HRV and PRV are similar among analyzed stages, but only distinguish ST and V form R. Due to the fact that every time window where $F_R(k)$ falls within the LF band were excluded, PLF could be interpreted as sympathetic activity. In this way, there is an increase of sympathetic activity on ST and a decrease of sympathetic activity on V. According to rPHF there are no differences on parasympathetic activity during stress stages ST, SA and V.

Concerning about HF band centered at $F_R(k)$, both HRV and PRV indices can distinguish between relax and prerelax stages (PRB and PRS). However, between R and V, PRV indices did not show significant differences while most of the HRV indices did. On the other hand, PRV indices showed significant differences between R and SA while none of HRV indices did.

Pulse arrival time (PAT) can be defined as the time that the pressure wave takes to propagate to the periphery from the time that a beat is detected at the ECG signal. PAT variability is the difference between HRV and PRV. During stress stages (ST, SA and V) there is not significant differences between HRV and PRV. In contrasts, most of the indices showed significant differences between PRV and HRV on relax stages (SA, ST, V). These results suggest that PAT variability is higher during relax, that could be explained by a low respiration frequency.

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