Investigating Phasic Activity of Time-Varying High-Order Spectra: A Heartbeat Dynamics Study during Cold-Pressure Test

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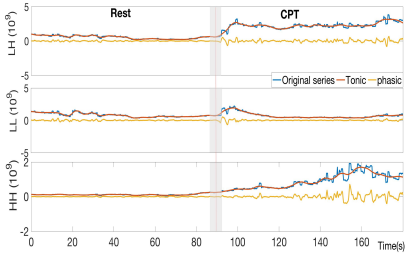
Background and Aim: Nonlinear analysis of cardiovascular variability series has been recognized as a valid tool for the assessment of health and disease states. Recent modeling advances successfully derived time-varying estimates of nonlinear heartbeat dynamics, whose quantifiers mainly rely on first-order moments (i.e., average in time). Nevertheless, while these metrics account for the information carried by the tonic (slow trend) nonlinear dynamics, they fail to quantify potentially meaningful information nested in the superimposed phasic (high-frequency) activity of the series. In this study, we investigate whether new metrics derived from phasic activity of time-varying bispectra are able to track autonomic nervous system changes as elicited by a cold-pressure test (CPT).

Method: Instantaneous bispectral measures are derived from nonlinear point-process modeling of heartbeat dynamics, fitted on ECG series gathered from 22 healthy volunteers undergoing sympathetic elicitation through the CPT. Instantaneous phasic bispectral activity is derived using wavelet decomposition, and quantified using the area under the curve (AUC) and variance (VAR) as a second order moment.

Results: Results show that phasic components of low-frequency (LL) instantaneous bispectral measures significantly change between resting and CPT states. Exemplary dynamics from one subject are shown in the right figure. The calculated AUC and VAR of the phasic phenomenon during resting state were $(6.04 \pm 5.62) * 10^{10}$ and $(4.22 \pm 4.03) * 10^{8}$, respectively, whereas they were $(2.25 \pm 1.64) * 10^{10}$ and $(1.17 \pm 1.02) * 10^{8}$ during CPT, demonstrating statistically significant discrimination between the two before and after stimulus phases (p-values of 0.026 for AUC, and 0.045 for VAR, gathered from Wilcoxon non-parametric test for paired data).



Conclusion: Phasic activations of bispectral estimates carry meaningful information for the nonlinear assessment of sympatho-vagal regulation to the heart. This study poses a foundation for a novel signal processing framework to investigate time-varying nonlinear dynamics of cardiovascular systems.