

### ICCAI 2007 Abstract

#### **Cardiopulmonary Variability During Staged Incremental Exercise Utilizing a Novel Continuous Individualized Multiorgan Variability Analysis (CIMVA) System**

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##### **Objectives:**

We hypothesize that complex physiologic dynamics are dependent on the integrity of the system generating them. Therefore, our objectives are to: (a) develop a novel system for continuous individualized multiorgan variability analysis (CIMVA) focused on cardiac and pulmonary rhythms, in an effort to track emergent properties over time of complex physiologic systems; and, (b) test the CIMVA system by evaluating changes in cardiopulmonary variability (CPV) during controlled physiologic stress, namely staged incremental exercise in healthy subjects.

##### **Methods:**

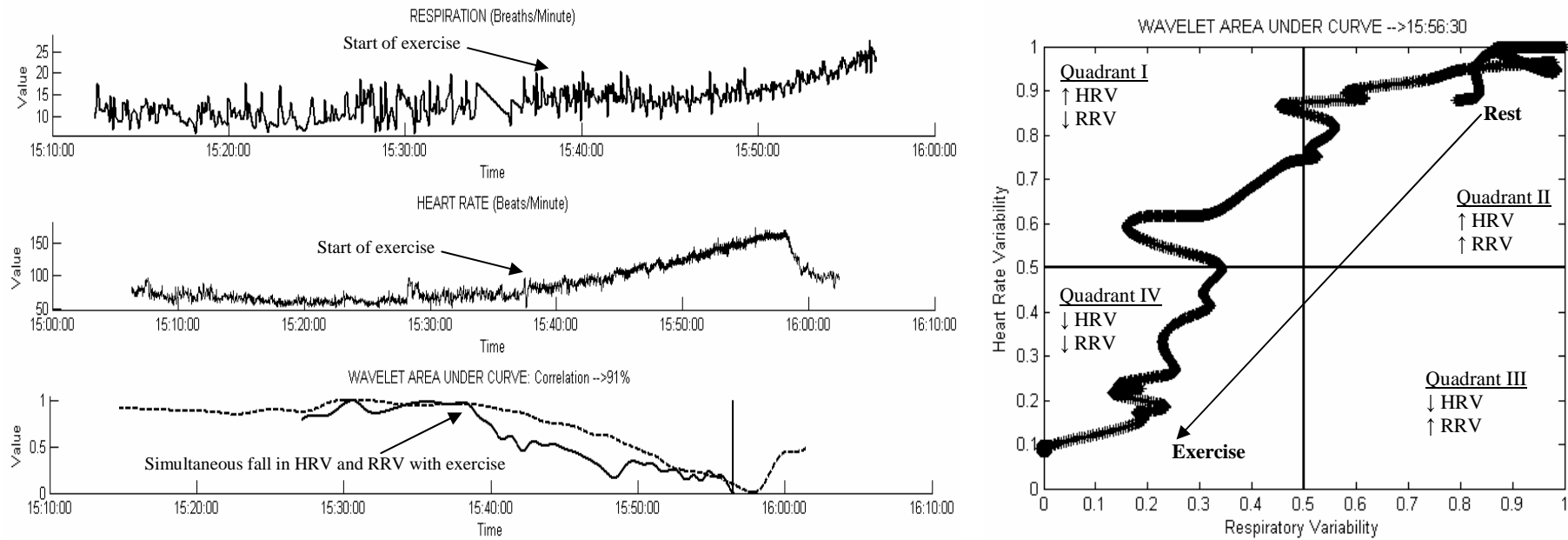
The CIMVA system (developed in Windows<sup>®</sup> Matlab<sup>®</sup>) comprises algorithms for computing and visualizing mean, standard deviation, location of non-stationarities, fast Fourier transform (FFT), sample entropy (SampEn), multiscale entropy (MSE), wavelet analysis, detrended fluctuation analysis (DFA), kurtosis, skewness, power law analysis, and time irreversibility statistics. To accomplish continuous variability analysis over time, a *roving window* approach is used, whereby a window of user specified *width* and *step* marches through the input signal, computing and time-stamping the above variability metrics at each *step*, thus creating multiple variability time series. Interval-in-time variability (instantaneous) and change in variability over time (evolution) are displayed on two parallel monitors. CPV is computed and visualized by synchronizing cardiac and pulmonary variability data streams, followed by plotting their "time evolution" on an X-Y plane. To test the CIMVA system, staged incremental exercise tests were performed on healthy volunteers (N = 8), during which continuous heart rate (Brytech<sup>®</sup>, 500 Hz EKG System) and respiratory rate (Respironics<sup>®</sup>, 200 Hz Capnograph System) data were harvested. For analysis, EKG waveforms were converted to RR' time series using Hamilton-Tompkins *QRS detection algorithm* whereas end-tidal CO<sub>2</sub> waveforms were converted to breath-to-breath time series using a novel *breath detection algorithm*.

##### **Results:**

The CIMVA system demonstrated robustness in continuously analyzing, visualizing, and storing CPV associated with heart and respiratory rate datasets. A reproducible decrease in wavelet, DFA, and power law CPV was observed with exercise for all subjects and this decrease was progressive and continuous (Figure 1). Certain measures of CPV namely FFT, power law, SampEn, and MSE demonstrated higher sensitivity to nonstationarity in the analyzed data, wherein the progressive decrease in CPV was less pronounced and not continuous. The remainder of the variability statistics computed by the CIMVA system, conformed to existing hypotheses regarding characteristic changes in CPV due to mechanical loading or exercise.

##### **Conclusions:**

We conclude that an automated analysis of continuous individualized multiorgan variability, utilizing a plurality of variability analysis techniques simultaneously is feasible, reproducible, and allows us to study the change in multiorgan variability over time, a novel measure, in a comprehensive and accurate manner. A reduction in overall CPV associated with increasing levels of exercise is evident across the population studied. This software analysis has several clinical applications with promise towards the development of a real-time diagnostic and predictive multiorgan variability analysis system.



**Figure 1:** Assessment of wavelet-based heart rate variability (HRV), respiratory variability (RRV), and cardiopulmonary variability (CPV) during a staged incremental exercise test. The top panel on the left displays the respiratory rate (RR) in breaths per minute and the middle panel displays the heart rate (HR) in beats per minute - both measured simultaneously. The bottom panel on the left displays the normalized individual wavelet-based variabilities for the RR and HR signals – the solid plot displays RRV while the dotted plot displays HRV. There exists a strong correlation of 91% between the wavelet-based HRV and RRV as depicted in this bottom panel – both variability curves tend to drop simultaneously after the initiation of exercise. The normalized four quadrant plot on the right, characterizes the evolution of CPV which shows a progressive and continuous decrease from rest to exercise – from quadrant two (high HRV, high RRV) to quadrant four (low HRV, low RRV).