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Application Note 267 Wireless Noninvasive Cardiovascular Reactivity Measurement

This application note introduces the BioNomadix System, a wireless, multi-variable, recording system for the purposes of physiological research and education. Measurement variables include ECG, EEG, EGG, EOG, EMG, Skin Temperature, Respiratory Effort, Electrodermal Activity, Pulse Plethysmography, Tri-axial Acceleration and Impedance Cardiography.

Overview

A subject's cardiovascular response (reactivity) to perceived stress is an important risk factor for determining the potential of cardiovascular disease. Consequently, measurement of cardiovascular reactivity is an important metric for physiological research. When performing cardiovascular measurements on ambulatory subjects, the ability to collect meaningful data can be seriously compromised by motion artifact, such as occurs regularly while walking, talking and breathing. Accordingly, certain methods must be used to reject spurious data. An important tool for "data cleaning" is the ensemble average. This is a signal averaging method whereby cyclic physiological data is consecutively averaged over some number of cycles or seconds. Usually, the averaging time window chosen is something less than one cycle. For cardiovascular measurements, typically the peak of the QRS interval of the ECG, the "R-wave peak" is used as a synchronization marker to reference the averaging process on other simultaneously collected data channels, such as blood pressure, Z or dZ(t)/dt. The BioNomadix Systems was evaluated for performance when ensemble averaging impedance cardiograms for the purpose of determining cardiovascular reactivity to stress.

Setup

The BIOPAC Systems "BioNomadix" series of wireless physiological transmitters and receivers were used for the evaluation. Two transmitter/receivers were used, ECG/Respiration (BIOPAC: BN-RSPEC) and Noninvasive Cardiac Output (BIOPAC: BN-NICO). The recorded variables were Respiratory Effort, ECG, Thoracic Impedance (Z), Derivative of Thoracic Impedance (dZ(t)/dt). Derived variables were BPM and dZ(t)/dt maximum.

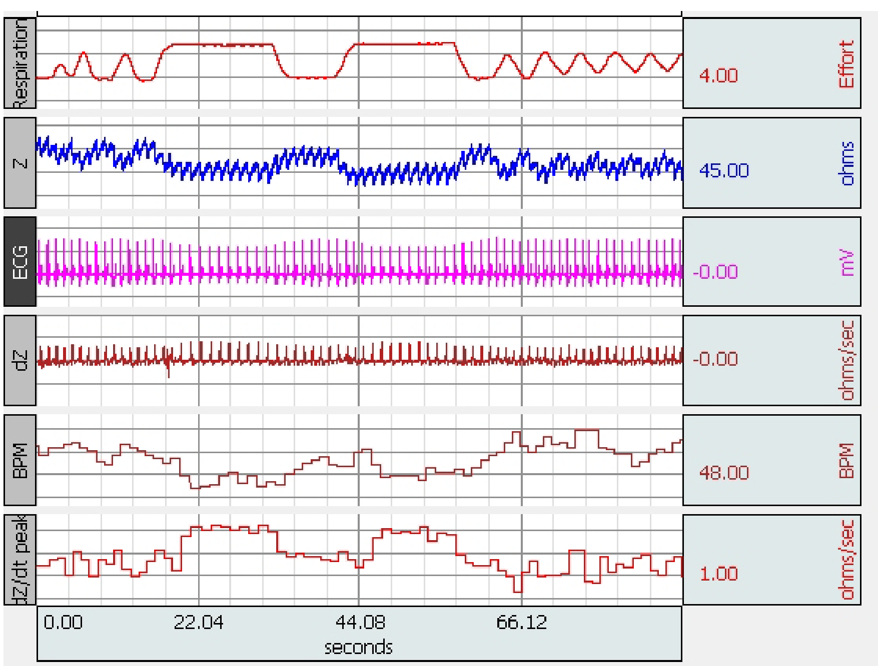

Figure 1: Wirelessly recorded physiological variables from subject

Dual tetrapolar-configured disposable spot electrodes were used to record cardiac impedance. Two electrodes at the top of the neck were connected together and used to inject current from the BN-NICO. The same current was returned by the combined pair of electrodes lowest on the torso. Voltage monitoring was performed using the two linked pairs of electrodes on the base of the neck and the pair level with the xiphisternal junction. A pair of spot electrodes were used to record ECG (Lead I). A single respiratory effort transducer was used to measure thoracic respiratory effort. The subject wore a specially designed tunic (BN-SHIRT-size) that held both small BioNomadix amplifier/wireless transmitters close to the torso.

The equipment was setup as indicated in Figure 2.

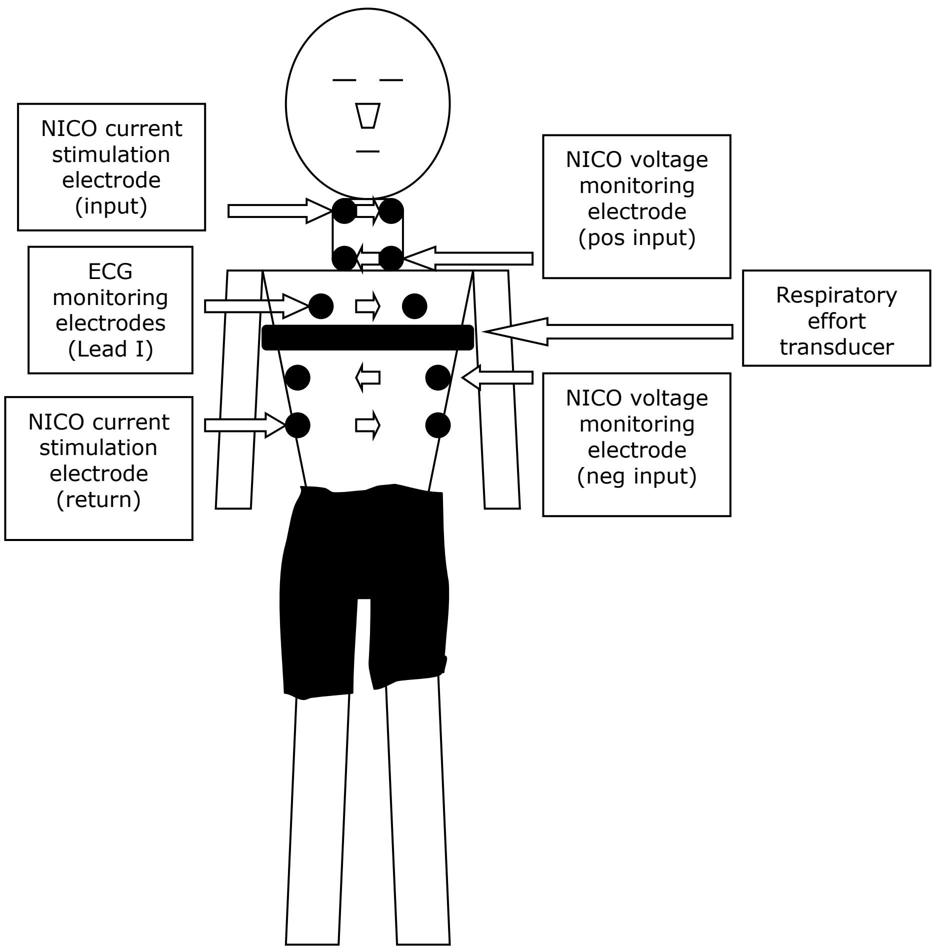

Figure 2: Electrode and transducer locations

Data Recording & Results

Data was collected for approximately 90 seconds, during which time the subject was seated and performing breathing exercises which involved active and inactive periods of respiratory effort.

The BN-NICO amplifier/transmitter returned values for Z (torso impedance magnitude) and dZ(t)/dt (torso impedance derivative). These values were band-limited from DC to 10Hz.

The BN-RSPEC amplifier transmitter returned values for respiratory effort (band-limited from DC-1 Hz) and electrocardiogram (band-limited from 0.5 Hz to 35Hz).

All data was sampled at the rate of 2000 Hz, using a 16-bit A/D converter (BIOPAC - MP150WSW).

The data was sectioned into 20-second intervals for ensemble averaging. Ensemble averages were performed in post-processing using BIOPAC Acq*Knowledge* software. R-wave peaks were located via Acq*Knowledge*'s built-in ECG classifier and these marked events were used to synchronize the averaging process. A time window of approximately 900 msec was used. Acq*Knowledge*'s impedance cardiography automatic scoring tools and associated pop-up measurements were collectively used to determine the location of the Q wave on the ECG cycle and also the locations of the B and X points on the dZ(t)/dt waveform.

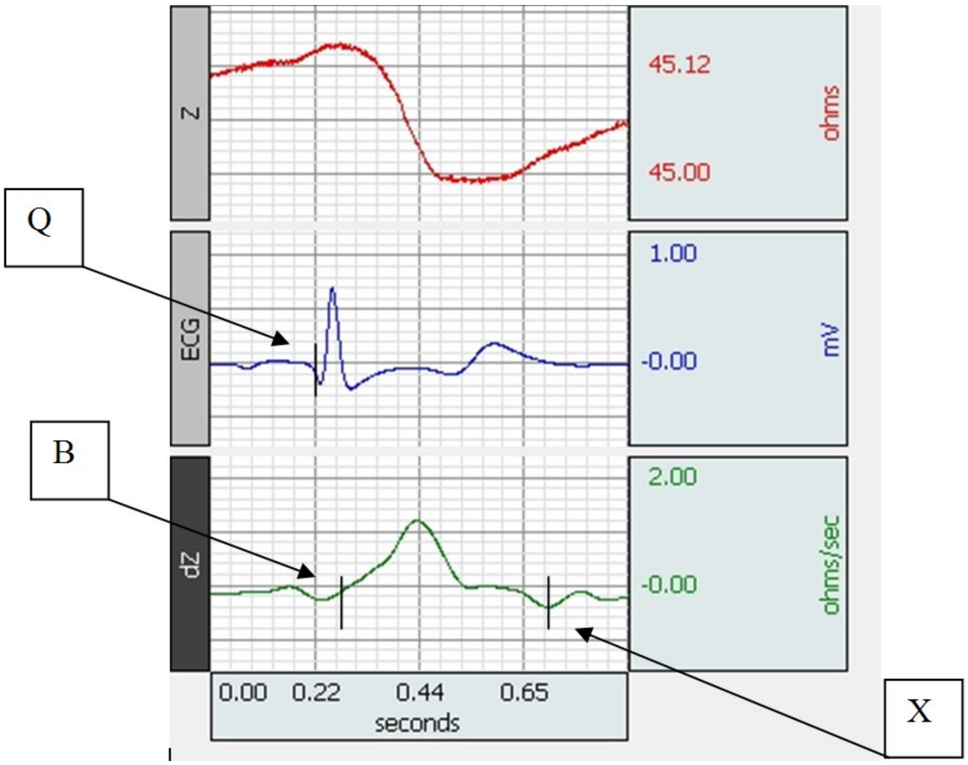

Figure 3: Ensemble averaged 20-second interval

An interesting aspect of the collected data illustrates the relationship between respiratory effort, heart rate (BPM) and dZ(t)/dt maximum. dZ(t)/dt maximum is proportionally related to stroke volume (SV - ml), as per the Kubicek equation:

$$\mathbf{SV = rho_b\ (L/Zo)^2 * LVET * dZ(t)/dt_{\ (max)}}$$

where SV - volume is the amount of blood the heart pumps with each beat (ml)

rho_b - resistivity of the blood (ohm*cm) – nominally 150 ohms*cm

L - distance between thoracic impedance voltage monitoring electrodes (cm)

Zo - baseline thoracic impedance between the voltage monitoring electrodes (ohms)

LVET - left ventricular ejection time (sec)

$dZ(t)/dt_{(max)}$ - absolute value of the maximum rate of change of the thoracic impedance

Note that in Figure 4, the BPM and dZ(t)/dt are somewhat inversely related. The high portions of the dZ(t)/dt waveform and the low portions of the BPM waveform correlate with the locations of inspired (and held) breath as shown in Figure 1.

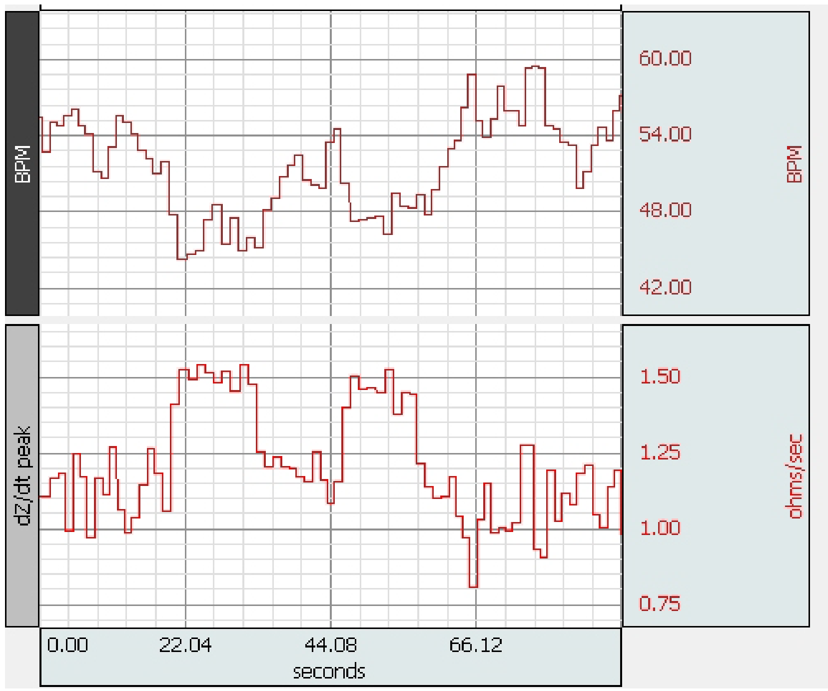

Figure 4: Comparison of BPM and dZ(t)/dt max data

A significant methodological concern in impedance cardiography is related to the impact of movement artifacts on recorded data. Ensemble averaging methods provide a strategy to remove these artifacts. Wearable and ubiquitous technology for physiological recording will likely be required to make use of these types of signal averaging techniques.

The BioNomadix System was able to perform real-time, beat-by-beat and ensemble averaged measurements related to cardiovascular reactivity, including Heart Rate (bpm), Left Ventricular Ejection Time (B-X ms), Pre-ejection Period (Q-B ms), Electromechanical Systole (Q-X ms), Stroke Volume (ml) and Cardiac Output (l/min).

References

[1] A. Sherwood, M. Allen, R. Kelsey, W. Lovallo and L. van Doornen, "Methodological Guidelines for Impedance Cardiography," Psychophysiology, vol. 27, 1990.

[2] R. Kelsey, S. Ornduff and B. Alpert, "Reliability of Cardiovascular reactivity to stress: Internal Consistency," Psychophysiology, vol. 44, pp. 216-225, 2007.

[3] R. Kelsey and W. Guethlein, “An Evaluation of the Ensemble Averaged Impedance Cardiogram,” Psychophysiology, vol. 27, 1990.