Autonomic Nervous System: Interpretation Problems in Assessment Methods

Abstract

Autonomic Nervous System (ANS) - the system that controls involuntary and necessary functions of the human body, such as beating of the heart, metabolic functions, gland secretion, *etc*. - is a fundamental part of human physiology and our nervous system. Stress is known to be a cause of ANS dysfunction potentially leading to many forms of illnesses, which can be evaluated accurately by measuring Heart Rate Variability (HRV). HRV became the center of much research conducted during the past few decades and home health devices were built with the aim to report on HRV and similar measurements so people could discover any abnormality in the rhythm of their heart. Such anomalies are difficult to be recorded with accuracy, but products monitoring them have become more improved in design - rather than comprehensive function - as part of garments. HRV is understood to have significant potential in measuring ANS function and cardiovascular function. However, scientists have difference of opinion regarding the efficacy of the traditional methods used for evaluating the various aspects of HRV. A new method for assessing ANS function is developed and implemented in the system named Body Health Analyzer (BHA). It brings Adaptation Effort, Adaptation Reserve, and Health State Index as central parameters for assessing HRV and cardiovascular function data. Data is recorded using specialized equipment connected to a computer and recording measurements for 5 minutes before the data is examined using a mathematical model and results are produced to inform the patient of the health state they fall into. The four states used in the model are Normal, Borderline, Pre-Disease (or Early Stage), and Pathology.

Problem Statement

Despite being a potential indicator of many health related problems due to the large array of specific parameters it records, HRV is yet to be used as a significant indicator in practical healthcare. This is due to the fact that experts have varied opinions on the efficacy of traditional methods and instruments that were developed in literature in the past. A new, comprehensive method is introduced in this regard.

Background

The American Heart Association's 1998 conference about heart diseases ended with the conclusion that a number of markers for cardiovascular inflammation indicated in literature to have potential could not be considered applicable due to mixed findings about their efficacy.[1] While the debate in the conference was directed towards cardiovascular disease in particular, the underlying argument is true for many areas in medical science literature. Standardization of metrics is a necessary step toward development of reliable treatment methods because expert consensus determines the acceptance of new treatments and products in the healthcare market.[2] A closely related example is the matter of application of Heart Rate Variability (HRV) data as a reliable indicator of a disrupted Autonomic Nervous System (ANS), which is a known indicator of cardiac health[3]. While literature built some consensus about using HRV as a reliable indicator of autonomic cardiac function in the recent decades, the methods and mechanisms devised in literature for measuring HRV and other aspects of ANS have not received universal acceptance among scholars.[4]

In the various sections that follow, this white paper discusses the process of development of a reliable technique to measure HRV based on a mathematical model that determines the overall condition of the patient's ANS and puts the patient in one of the four health states that the BHA method registers: Normal, Borderline, Pre-Disease, and Disease.

Available HRV Measurement Devices

In recent decades, large numbers of studies have been directed towards discovering various areas of inquiry related to HRV. Consequently, HRV has become a central factor for healthcare research so much so that very few areas of biomedical science currently do not use it to determine the connection between the body's autonomic functions and human pathology.

In the era of convenient technology integration into medical practices, HRV measurement is something product manufacturers in the industry continue to focus on with greater investments and research. As a result, a number of products have emerged in the market with considerable promise of accuracy. However, they have not managed to produce expert consensus on the matter of interpretation of measured numbers.

Incidentally, to justify the development of BHA, it is reasonable for this paper to first discuss already available methods and instruments along with their assumed shortcomings due to controversies regarding reliability of interpretation of much of these data.

Physicians and healthcare professionals have conventionally relied on Electrocardiography (ECG) as the primary source of HRV related data[5]. However, most products available for

[1] Pearson *et al*. (2003)
[2] Pacini *et al*. (2016)
[3] Alvares *et al*. (2016)
[4] Alvares *et al*. (2016); Berntson *et al*. (1997)
[5] Tsoi *et al*. (2017)

practitioners to examine real-time state of ANS use other approaches and data to reach their findings.

INTELLEWAVE:

IntelleWave is one such product. It measures HRV and blood pressure of the patient with gauging for both the Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS). The device uses power spectral analysis for quantitative measurement of HRV. The findings produced by the analysis are presented in the form of a clustered chart that divides the findings in high and low frequency components.

Intellewave promises to measure the state of the patient's autonomic balance (between SNS and PNS) with an in-depth examination of multiple factors using CPT codes to assist practitioners in diagnosing multiple ICD-9 problems.

To be specific, the system Intellewave is built on measures the "intensities of high frequency and intensities of low frequency of HRV and displays them on the monitor in the said cluster. The company claims these high and low frequency intensity levels are cited in research as indicators of the state of the patient's PNS and SNS respectively.

This product allows practitioners to measure HRV trends using three tests: "Orthostatic intervention (lying-to-standing test); valsalva maneuver combined with deep breathing; real-time HRV assessment (1 or 2 channels)." In product description, the manufacturer requests practitioners to not rely solely on its test results to diagnose patients but verify the findings of the product with "other clinical diagnostic methods."[6]

INNER BALANCE & EMWAVE2 BY HEARTMATH:

HeartMath has released a number of products for measuring well-being and status of overall physical and autonomic health of patients. The Inner Balance monitor is a product that uses HRV data to give practitioners insight into the current state of the patient's ANS balance levels. The product measures HRV and provides its results in wave patterns with the patient's history of results about "Coherence."

Supported by a mobile device application for Android and iOS, Inner Balance provides real-time HRV data so the practitioner can use the findings to help patients achieve higher coherence levels, which is the manufacturer's jargon for autonomic balance.

The Inner Balance system posits that the patient's emotional state drives their overall inner health and the use of the system's findings can help practitioners help patients "shift into a state of balance, self-reliance and renewing feelings, such as appreciation and compassion."

[6] IntelleWave (2018)

The emWave2 handheld system further probes into the connection of HRV and feelings. The product is marketed as an instrument to help patients monitor their heart rhythms so they can change their feelings to more positive ones for a better life experience and greater "emotional composure and clear thinking."

According to the company's own description, "Coherence is an optimal physiological state shown to prevent and reduce stress, increase resilience, and promote emotional well-being."[7]

HEART RHYTHM SCANNER PE & HRV LIVE BY BIOCOM TECHNOLOGIES:

Biocom Technologies is another respected company that has manufactured multiple products related to monitoring cardiovascular health. Two of these products in particular use HRV data to provide practitioners and patients considerably detailed information about their autonomic balance.

The Heart Rhythm Scanner Professional Edition is built to provide practitioners a variety of data for assessing the patient's autonomic well-being. The Heart Rhythm Scanner PE measures PNS and SNS indicators to measure autonomic balance and ANS regulatory function. It helps practitioners in designing "HRV evaluation protocols" for trials aimed at in-depth research into the patient's autonomic state. The system allows practitioners use modes for "resting autonomic balance assessment, cardiovascular health, and baroreflex function."

The HRV Live monitor from Biocom Technology is another product with similar, but more limited, capabilities than the Heart Rhythm Scanner PE. It allows for continuously monitoring HRV parameters and provides HRV data in sufficient detail and lets practitioners view them in various printable graphs that provide data trends and comparisons.[8]

KUBIOS HRV:

Kubios is another medical devices manufacturer focused on monitoring instruments for clinical and home use, catering both practitioners and patients. Kubios HRV is a software system that allows practitioners to connect an ECG monitor with their computer and have Kubios HRV record the data for various tests related to cardiovascular health and autonomic well-being of the patient.

Once the data is stored, Kubios HRV analyses it in a number of modalities and provides outputs in graphical representation, which can then be downloaded as more recognized file formats for printing (PDF) and further statistical analyses (CSV and MAT).

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[7] HeartMath (2018)
[8] Biocom Technology (2018)

The practitioner using the device can set assessment parameters in advance to get specific results related to the nature of their inquiry.

The software system can be purchased in two sets of features: standard and premium. Depending on the package you purchase, the extent to which you can benefit from the system's capabilities will change.[9]

Development of the Body Health Analyzer

BHA was developed to provide medical practitioners with an accurate method to measure patient well- being using, and interpreting standard HRV data. Founded on a concrete mathematical algorithm that connects HRV data points with the overall state of health of the patient, the BHA puts the patient in one of its four *states*, which were previously listed and shown in Fig. I below. The calculations also show the probability of the patient at risk of being in the Pre-Disease or Disease state.

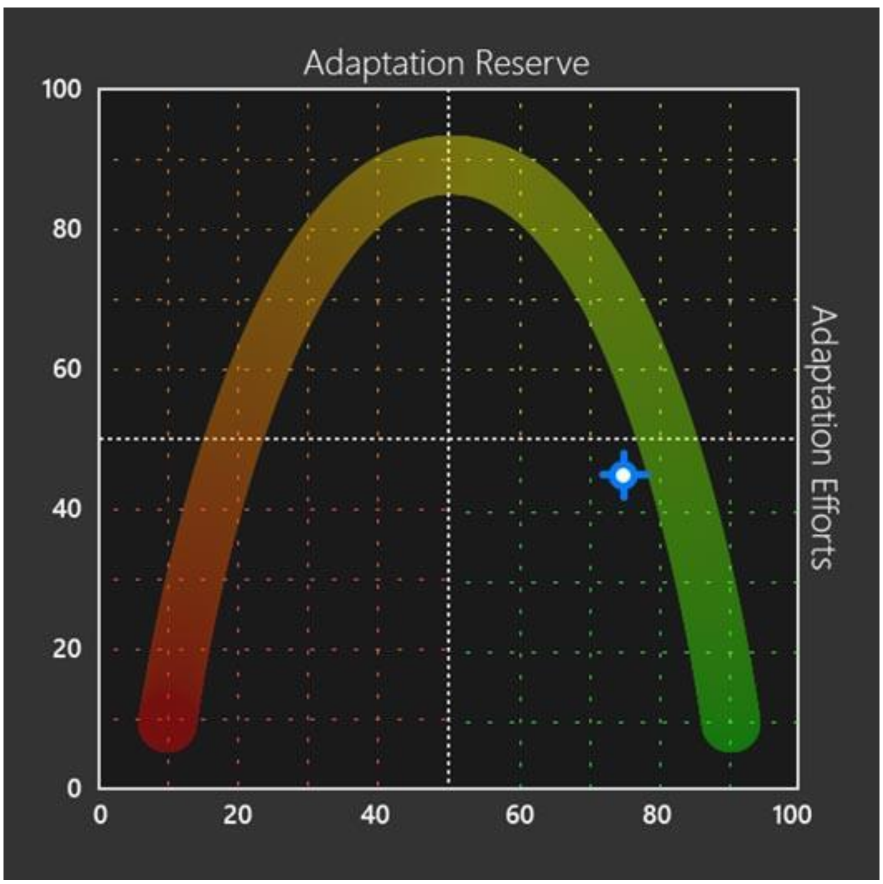


Fig. I: Path to Disease and the Four States Studied by BHA

[9] Kubios (2018)

The foundations of BHA are linked with the extensive research of Professor Roman M. Baevsky, who dedicated decades of work to collecting data regarding the relationship between stress, HRV, and human health.[10] USSR continued multi-tiered programs in space medicine research between 1960s and 1980s, and many scientists published studies to report the link between HRV, ANS, and various other autonomic indicators of health.[11] Heading the medical division of Soviet space program, Prof. Baevsky monitored vital signs telemetrically.[12]

During the 1960s, the focus of his studies was the impact of extreme stress on HRV, and he discovered a direct and positive correlation between levels of stress and decreased HRV values.[13] His experiments showed a significant decrease in HRV values with significant increase in stress. Consequently, he also discovered HRV values of his subjects increased as stress subsided.

BHA is fundamentally a mathematical model that is informed by the patient's HRV data to give two output parameters Adaptation Effort and Adaptation Reserve that can be interpreted more univocally. Both of these parameters act as clear physiological indicators individually. However, when combined, they produce more meaningful information, which is the current health state of the patient represented by Health State Index. BHA determines the current state of the patient out of the four states used in Fig. I and listed above.

BHA is a compact device with the software algorithm programmed into the hardware to enable ready-to-use capability straight out of the packaging. The device utilizes a new quantitative method for practitioners to evaluate risks in borderline, pre-morbid and pathological states while assessing the autonomic health of the patient.

- This method may utilize recording of electrocardiograph (ECG) or photoplethysmograph (PPG) signal at rest for 5 minutes using respective recording devices interfaced with a personal computer.
- Recorded ECG or PPG signals are analyzed using specific known algorithms to measure beat-by-beat heartbeat intervals.
- The algorithms determine these parameters of autonomic balance and overall physiological health of the patient: heart rate (HR), tension index (TI), pNN50 and HF%. These parameters are used to calculate the Adaptation Effort (AE), reflecting the degree of tension of regulatory mechanisms and their Adaptation Reserve (AR) using canonical discriminant function equations.
- The obtained values of AE and AR are used in the original manner to calculate the values of respective discriminant functions and identify the four types of states mentioned earlier and finally estimate the Health State Index (HIS).

[10] Baevsky, Petrov & Chernikova (1998)
[11] Baevsky (1972; 1975); Baevsky, Zamotaev & Nidekker (1971); Kudryavtseva (1974)
[12] Mayorov & Baevsky (1999)
[13] Parin, Baevsky & Gazenko (1965a); Parin, Baevsky & Gazenko (1965b)

- The results of this assessment may be visually presented in the form of a special diagram with orthogonal coordinates of AE versus AR. The plot area of this diagram is divided by two orthogonal axes into four quadrants defining those four states.
- A resulting dot is placed on the diagram in accordance with the respective values of AE and AR obtained from the measured data indicating the current condition of the mechanisms of physiological adaptation.
- The obtained values of probabilities of risk of developing four respective states may be presented in the form of proportional bar diagram. Each probability of respective state may be presented in a specific color intuitively associated with the respective state.
- As the research data suggested, when a large number of data is collected, the vast majority of AE and AR readings tend to form a distinct path from the normal state to disease state having the arch shape. The HSI parameter is mainly a reflection of the projection of a dot formed by the pair of AE and AR readings on this path.

With multiple tests using the BHA method over time, practitioners can evaluate the dynamics of changes in data of the adaptation mechanisms and risks of developing respective states. These dynamics are evaluated using standard methods of regression analysis. The obtained results of this analysis may allow for making conclusions about the dynamics of changes taking place along with their degree and direction. Depending on the number of assessments performed over time the level of statistical significance of such analysis can be estimated to a remarkably high level of accuracy.

Practitioners can then continue to use the regression analysis and mathematical extrapolation models of BHA and determine the forecast of order among the variables included in the calculations along with the confidence values of the forecast.

BHA's Efficacy

BHA has been established in a time when no reliable instruments are available for practitioners to comprehensively monitor the internal health of the patient during an assessment. With the four-state evaluation technique and the mathematical analysis model, the product allows practitioners to get multi-faceted data and a conclusive picture of their health state.

BHA is based on technology that can be made part of a person's life using a number of convenient applications. These may take the form of a wristwatch, a bracelet, or a smartphone accessory, among others. All these manifestations require is a sensor connected to record HRV data and transmit it to a computer with the ability to display data on a suitable monitor.

Incidentally, the BHA technology has been part of a long period of HRV research. Multitudes of studies have been based on it and research continues to fine-tune information that shows us the technology is highly useful and reliable. A number of scientists from Russia and Western Europe have worked together for numerous research studies with focus on HRV.

One such study was the MARS-500 international project conducted several years ago. Its purpose was to simulate a long space flight of a small crew to Mars. The study focused on measuring stress levels of crew members after they had been isolated from the rest of the world on their Mars mission for 512 days using a specially designed compound. Although the study did not expose the subjects to zero gravity conditions, the researchers studied the effects of stress on the crew caused by isolation, measuring stress levels every week using the BHA method.

Demonstrated below in Fig. II is the data record of one of the crew members, illustrating the dynamics of BHA output recorded during the project.

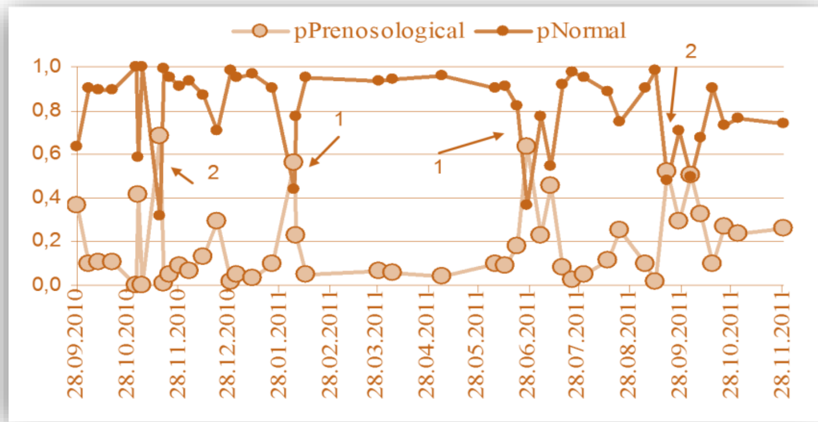
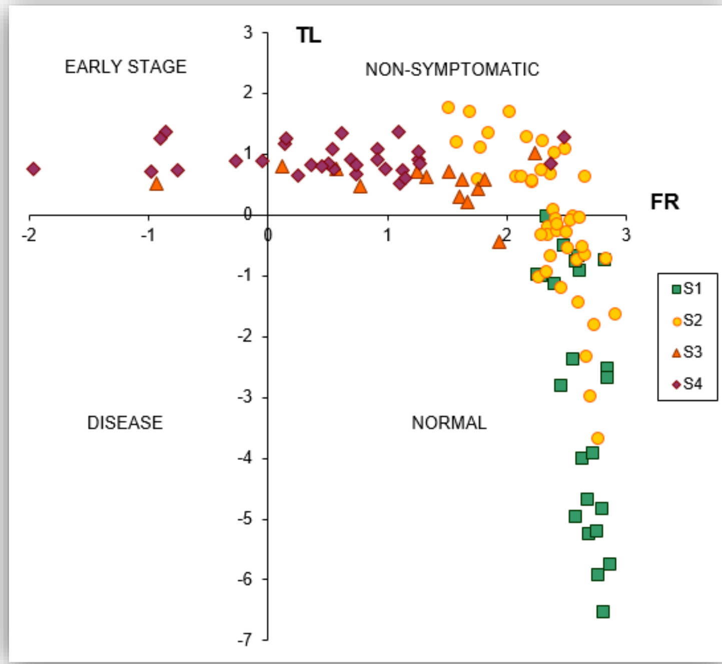


Fig. II: BHA Based Data Record of a MARS-500 Study Subject

The image shows the probabilities of the subject in Normal and Borderline states. As the data shows, the person studied was most of the time found to be in a healthy state. However, two long periods marked by the digit 1 show when the crew member experienced considerable work related stress with elevated blood pressure and other clinical symptoms. Two other points marked by the digit 2 correspond to the crew member having seasonal respiratory problem.

The illustration in Fig. III below demonstrates the application of BHA technology on 4 coworkers whose health states were studied for 12 months. S1 is a 21 years old male with no apparent health issues. S2 is a 50 years old male subject with no apparent health problems except occasional moderate stress at work. S3 is a 49 years old male subject who is overweight and early prediabetic. Lastly, S4 is a 49 years old male who experienced occasional minor abdominal pains that progress over the study period. S4 was eventually diagnosed with a stomach polyp, removal of which caused steady improvement in health, as shown in the figure below.



Fig, III: 4 Coworkers Data via BHA

Further Inquiry

BHA is the result of decades of research and tried and tested methods out of the field, and the work will continue so that the system can be improved upon with time.

Any inquiries about the technology and its implications can be sent to Binacor LLC via email: john@bodyhealthanalyzer.com

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