Total Wavelet Entropy Analysis of Cyclic Exercise Protocol on Heart Rate Variability

A. M. Petrock[1], Dr. S. Reisman[1], Dr. I. Dardik[2]
[1]Department of Biomedical Engineering, New Jersey Institute of Technology, Newark, NJ
[2] Lifewaves International, Califon, NJ

Abstract – **Cyclic exercise has been shown to have a positive impact on health. This study investigated the efficacy of a novel exercise protocol on heart rate variability, which is an indication of the body's ability to respond to stress. The total wavelet entropy parameter indicated an increasing trend in the free energy, or information content, of the signal in the high and low frequency ranges, as well as over the entire range of frequencies in the signal. This suggests that a cyclic exercise protocol is training the body's natural exertion/recovery ability due to the increase in variability in both the high and low frequency ranges.**

I. Introduction

It is a rising trend in various areas devoted to the study of non-linear dynamics to use a wavelet analysis of a signal to generate a set of new, spectrally reduced time series for analysis. This method can shed light on the activity in specific frequency ranges, and changes in the information content of a signal. It may also yield important new information regarding the efficacy of various treatment protocols.

The cyclic exercise protocol has been suggested as a means of enhancing health by training the body's natural response to stress and relaxation. This stress/relaxation cycle is controlled by a complex interaction of the branches of the autonomic nervous system. It is believed that by altering the body through exercise, the changes reach into the nervous system response. This study supports this theory.

Cyclic Exercise

Cyclic exercise has been shown to provoke significant improvements in health at many levels. In Parkinson's subjects, it has shown significant reduction in tremor and significant increases in anti-inflammatory signal molecules [1,2]. This study assessed the impact of the implementation of cyclic exercise in healthy women.

This study was performed to test the efficacy of the cyclic exercise protocol. This protocol trains the subjects not only in the stress (exertion) phase, but also in the relaxation (recovery) phase. This wave-shaped training of opposing phases of exertion (increased heart rate) and recovery (returning to a resting heart rate) is why the protocol is referred to as cyclic.

Heart Rate Variability

The study of Heart Rate Variability (HRV) is focused on understanding the complex interactions of the sympathetic and parasympathetic nervous systems using the electrocardiogram (ECG). Traditional analysis methods involve investigation of the spectral activity in the high or low frequency regions of an interpolated inter-beat interval signal. This method assumes stationarity of the heart rate variability signal, and does not investigate the non-linear behavior of the branches of the autonomic nervous system. It is the non-linear behavior of these oscillatory systems that results in the heart rate variability recorded in the ECG, and thus, is of interest in determining the change in the health of a subject as a result of the exercise protocol.

Total Wavelet Entropy

The Total Wavelet Entropy (S_{wt}) parameter has been used to study the classical limit of two coupled harmonic oscillators. Because the parasympathetic and sympathetic nervous systems can be viewed as coupled harmonic oscillators, it was decided to use this S_{wt} approach to assess changes in the autonomic nervous system.

II. Methods

Subject Selection

Eleven healthy female subjects, ranging in age from 32 to 58 years of age, participated in this study. Exclusion criteria included chronic drug or medication use, tobacco use, history of chronic illness or if they engaged in an exercise regimen on a regular basis.

Exercise Protocol

The eight-week study was specially prescribed for the individual, according to a baseline evaluation of maximal heart rate response exertion. The subjects performed the exercise three times per week, for three weeks, and then rested on the fourth week, and repeated the same series beginning at week five. The protocol involved a series of activation-relaxation cycles. The subjects were given a series of target heart rates, which they were instructed to achieve within a certain window of time. The timing and intensity of a given cycle within one session was related to the timing and intensity of previous cycles and sessions.

Data Acquisition and Treatment

The subjects were placed in the supine position for 8 minutes. During this time, they were asked to breathe in a controlled way, at a rate of approximately 12 breaths per minute, following a breathing protocol which indicated when to inhale and when to exhale. A Polar watch (Polar Electro Inc., Woodbury, NY) recorded the time between subjects' heart beats, yielding an inter-beat interval (IBI).

The inter-beat interval was reverse interpolated to generate an interpolated inter-beat interval (IIBI), sampled at a rate of 250 Hz. The IIBI was then analyzed using the wavelet and statistics toolboxes in Matlab v. 6.5.

Data Analysis

The data were analyzed in several ways. The continuous morlet wavelet transform was used to decompose the IIBI signal into eleven distinct frequency components. These components corresponded to a frequency band from 0.0099 to 10.16 Hz.

The Total Wavelet Entropy measure was obtained in accordance with the algorithms described in [3]. The calculation was based upon the Shannon energy principle, defined by

$$S_{wt} = -\Sigma[Pa*\ln(Pa)], \quad (1)$$

where Pa is the probability distribution, or relative wavelet energy, for a given scale, a. Scale has an inverse relationship to frequency. The scale-dependant probability distributions are representative of a scale density function which can be used to assess frequency activity. Further, a normalized wavelet energy, Q, was calculated based upon the equation

$$Q = S_{wt}/\ln(a), \quad (2)$$

where a is the maximum scale used in the analysis. This measure indicates the level of free energy, or information, contained in the signal. The higher the index, the increased amount of information and complex interactions is contained within the signal.

For the application of this technique to Heart Rate Variability, specific frequency bands were used. HRV traditionally looks at activity in the high frequency range (0.14 through 0.4 Hz) as representative of the activity in the parasympathetic nervous system. Activity in the low frequency (0.01 through 0.14 Hz) range is viewed as a reflection of the sympatho-vagal interaction, or the interaction of the parasympathetic and sympathetic branches of the autonomic nervous system. For this study, the Total Wavelet Entropy measure was calculated for the low and high frequency ranges, as well as the total signal S_{wt}. This was done by modifying (1) and (2) to investigate only the scales of interest, as follows:

$$S_{wt}\_LF = \sum_{a=7}^{11} Pa*\ln(Pa), \quad (3)$$

$$S_{wt}\_HF = \sum_{a=6}^{7} Pa*\ln(Pa), \quad (4)$$

$$Q\_LF = S_{wt}\_LF/\ln(5), \quad (5)$$

$$Q\_HF = S_{wt}\_HF/\ln(2). \quad (6)$$

These equations then yield values for the high and low frequency components.

IV. Results and Discussion

All of the data indicated increases in the free energy. The low and high frequency, as well as total energy parameters displayed increasing trends. The mean value of the total wavelet entropy, S_{wt}, increased from the baseline value of 0.8132 to 0.8548. S_{wt}_LF increased from 0.6978 to 0.7110, and S_{wt}_HF increased from 0.1116 to 0.1386. The normalized values of Q, Q_LF and Q_HF increased from 0.3391 to 0.3565, from 0.6532 to 0.6535, and 0.1016 to 0.1262, respectively. Note the increase in all parameters, regardless of frequency range, from the baseline values to the post study assessment taken only eight weeks later.

The cyclic exercise protocol is in contrast to traditional aerobic exercise, which trains the exertion aspect of the body continuously for a specific amount of time. Typical aerobic exercise has a duration of approximately .75 to one hour, initiated with a controlled warm-up phase and followed by a controlled cool-down phase. At no point does traditional exercise allow the body to enter the exertion or relaxation phase naturally.

The theory that the body's natural responses are being trained in the cyclic protocol is verified by the increase in free energy, or information content, of all measures in this study. If only one of them showed an increase, it would indicate that a branch of the autonomic nervous system was not being affected in the theorized manner by the cyclic exercise protocol. Increased free energy indicates increased variability, or disorder, in the system, which indicates increased robustness to perturbations of the systems involved.

References

[1] Cadet, P , et al., "Cyclic Exercise Induces Anti-Inflammatory Signal Molecule Increases in the Plasma of Parkinson's Patients," International Journal of Molecular Medicine, 12: 0-00, 2003

[2] Rymer, M. et al., "Physical and Emotional Effect of Cyclic Exercise on Parksinson's Patients," Puijo symposium, Kuopio, Finland, 2001.

[3] Kowalski, A.M., Martin, M.T. Plastino, Proto, A. and O.A. Rosso. Wavelet Statistical Complexity Analysis of the Classical Limit. Physics Letters A, Vol. 311, Issues 2-3, May 2003, pp 180-191.