A Fast Fourier Transform Analysis of Time Series Data of Heart Rate Variability During Alfa-Rhythm Stimulation in Brain Entrainment

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ABSTRACT
It is well known that the decrease of the Heart Rate Variability (HRV) is related to a number of important pathologies involving cardiovascular system as well as psychological and psychiatric disorders. In such case a prompt recover of HRV and, in particular, of parasympathetic modulation is required in the ANS (Autonomic Nervous System). In order to pursue this objective in the present paper, the physical technique of the brain entrainment has been used. We have recorded R-R time intervals estimated from the QRS complex in the ECG. One time the R-R signal has been recorded during rest condition of the subject and the second time during alpha brain stimulation. The following step has been to analyze the data performing the Fast Fourier Analysis that is able to quantify the ANS activity of modulation on heart rhythm. We have found that, respect to the rest case, alpha brain stimulation induces a constant improvement in the total power spectral density (and thus induces an increase in total heart rhythm variability) and in particular in the parasympathetic (HF) band spectrum. The result is of interest for further consideration by clinicians and researchers of brainwave entrainment (BWE) as basic therapeutic tool in so serious field of neurology and related pathologies.

Key Words: Fast Fourier Transform, FFT, analysis of time series data, HRV analysis, alfa rhythm brain stimulation, brain entrainment

Introduction
Brainwave entrainment (BWE) is a physical technique relating the use of rhythmic stimuli with the finality to induce a frequency-following response of brainwaves to match the frequency of the stimulus. This method is evidencing its importance in some specific fields as to improve cognitive functioning, mood, stress/anxiety, pain relief, headaches/migraines, behaviour, and premenstrual syndrome. The basic theoretical foundation in BWE is to stimulate the brain at the desired frequency via auditory tones, flashing lights, or a combination of both using isochronic, monaural, or binaural beats. Isochronic tones are evenly spaced tones that simply turn on and off. Monaural and binaural beats are presented as two tones with very similar frequencies, and the brain perceives a beat that is the difference between the two pitches. The pitches are presented together with monaural beats but fed separately to each ear with binaural beats.
For photic stimulation, most devices use lights or a flashing screen. Pulses of light can be presented as different waveforms or colours. Photic stimulation can be also presented independently to each eye or each visual field in order to more effectively target stimulation to the right or left hemisphere.

BWE sessions most commonly last from 20 to 60 minutes, during which the subject sits either with his/her eyes closed in a quiet setting or, depending on the kind of used session, with eyes open. Obviously, subjects with a history of epilepsy are advised against use of photic stimulation.

The first known clinical application of BWE goes back to the French psychologist, Pierre Janet, in the late 1800s. After the initial demonstration of Berger in 1934 on electrical activity recorded from the human brain, Adrian and Mathews showed that the Berger rhythm (alpha) could be further amplified by photic stimulation at the same frequency. In 1942, Dempsey and Morison found that BWE could also be induced by a tactile stimulus, and in 1959 Chaitran reported entrainment effects with an auditory stimulus. Psychological effects of BWE were further explored in 1946 when flickering light produced frequency-dependent sensations of pattern, movement and colour. The development of BWE tools increased largely starting with 1973. Oster's results evidenced the properties of the binaural beat. Research on the effects of BWE on pain, headaches, migraines, anxiety, and stress followed in the 1980s and expanded in the 1990s to include learning and memory, attention deficit hyperactivity disorder, learning disabilities, behavioural problems, and PMS. An excellent review and an historical account of the first authors and recent advances in this field are given in (Huang et al., 2008). Summarizing, it results that the presentation of a consistent rhythmic stimulus within 8 to 10 Hz causes brainwaves in the occipital lobe, parietal lobe, or temporal cortex to exhibit a frequency-following response that either resonates with the presenting stimulus or shows a frequency harmonic or a sub-harmonic of a stimulus.

Of course, it is clear that more research needs to be conducted to confirm the effectiveness of specific protocols to each outcome. The finality of the present contribution is to give support for further consideration by clinicians and researchers as BWE therapeutic tool.

We have followed the following procedure.

It is known that the section of the nervous system which controls the visceral functions of the body is the autonomous nervous system that regulates itself. This system tonically and reflexly influences blood pressure, peripheral resistance, cardiac frequency and cardiac debt. The heart is a central organ in the maintenance of homeostasis and in order to reach it, receives autonomic influences. One of its main characteristics consists of constant alteration of its beating frequency. The information reaches the central nervous system (nucleus tractus solitarius) through narrow and vagal afferent ways; is modulated and returns to the heart through fast vagal efferent fibers and slow sympathetic efferent ones. The resulting effect of these autonomic influences is the variability beat after beat of the instantaneous heart rate.

The physiological importance of such concept of Variability has been discussed by us in detail in some previous papers where we have given detailed methods for its investigation and quantification (Conte et al., 2009; 2009a; 2010; 2012). The neurocardiological function of the heart receives its information from the amygdala. In turn the amygdala receives it from the thalamus.

The quality of incoming information modifies the HRV and this is then transmitted through the body neurologically (back to the amygdala, the brain stem, and to higher cortical centres), hormonally, and biophysically. Heart Rate Variability (HRV) in heart acts as an extension and amplifier of the limbic system of the body.

In 1977 Wolf et al. were the first ones to demonstrate association between increases in the risk for post-infarct mortality with decrease of HRV. Actually, the capacity to vary the cardiac beat rate has the physiological meaning of adapting the Cardiovascular System to the several daily situations, from sleep to strenuous physical activity and strong cognitive or emotional engagement. The study of the HRV has allowed recognizing and characterizing some situations in which diseases affect the autonomic control. Some
authors have demonstrated that the decrease of the HRV is related to a higher index of cardiovascular morbidity and mortality implying in the presence of individual physiological dysfunction.

A healthy physiological system has the following characteristics: efficient neural control, rhythmic physiological variability within normal limits, greater response–potential to challenge, greater range of response behaviour. Attenuated physiological variability is associated with a lack of psychological and behavioural flexibility in response to environmental demand. A reduction in HRV is therefore not only an indication of a lack of physiological variability, but also in its broad sense a reflection of reduced psychological and behavioural flexibility.

The heart beat rate is a non-linear, complex, non-stationary and non-periodic signal (Conte et al., 2009; 2009a) subjected to fluctuations. The ideal fluctuation is a quite rhythmic increase and decrease in HRV which generates a continuous variability in time of the signal that roughly approximates a repeated sine curve. Actually HRV behaviour is typically a largely complex pattern (Conte et al., 2009; 2009a; 2010; 2012; Sandercock et al., 2005). The nature of the heart rate variability describes the particular rhythm of an individual heart beat characteristics, and this is related to a number of effects regarding other body systems. All other oscillating systems function, in fact, in accordance with the coherence or otherwise of the heart beat variability. Heart rate variability must be contained within some values for normal subject behaviour. Reduced variability is the first sign of increased subject risk (Sandercock et al., 2005).

Still, growing evidence suggests that alterations in autonomic function are related as example to the pathophysiology of panic disorder (PD). The risk of adverse clinical cardiac events is increased in patients with PD.

Autonomic nervous system (ANS) dysfunction and reduced HRV have been reported in a wide variety of psychological and psychiatric disorders as, in particular, anxiety and stress. Some authors recorded cardiac activity and assessed HRV in acutely hospitalized bipolar disorder and schizophrenia patients. Generally speaking, autonomic dysregulation is associated with more severe psychiatric symptoms, suggesting HRV dysfunction.

In conclusion, HRV is a very important marker of autonomic activity and thus a privileged observatory for a lot of disease conditions. Some of these conditions are very elusive and practically impossible to detect with reliable diagnosis methods. Some subjects may exhibit a psychological profile with a tendency to the introversion, anxiety and depression without showing psychological test values out of the normal established values. Other subjects may have tendency to develop pathologies with a relative lowering of the threshold pain as example in the headache, migraine. All such subjects may exhibit reduced HRV and thus enhanced risk factor. This justifies the interest in the development of analysis by HRV methods.

On this basis we attempted to experience if subjects with no defined diagnosis of anxiety and of stress or depression, not of sedentary style of life, but starting however with a reduced variability in HRV, when submitted to BWE therapy, reported a net improvement in HRV. If confirmed, this result should be of interest for further consideration by clinicians and researchers of BWE as basic therapeutic tool.

Materials and Methods
Ten patients, 5 males and 5 females, 25–40 years old in ascertained healthy condition were evaluated by STAI (State-Trait-Anxiety-Inventory) for state anxiety, by SII (Strong-Interest-Inventory) for stress, and BDI (Beck-Depression-Inventory) for depression, giving values at the boundary of the norm. Subjects had not sedentary style life and had normal weight, were tested not having other general medical, neurological and psychiatric diseases, and central nervous system acting without drugs assumption. A written informed consent was obtained before the experiment, after its approval by the local ethical committee. Subjects were instructed to abstain from caffeine, alcohol, and medication and to maintain their regular sleep–wake schedule on the 3 days before each experimental session. The experiment was conducted in accordance with the Declaration of Helsinki. The R-R tachogram recording was performed by plethysmography for five minutes in condition of absolute quiet and general comfortable condition for each subject, at rest in a quiet
room with soft distant and very weak illumination and spontaneous respiration. The recorded tachogram was subsequently analyzed in frequency domain by using Fast Fourier Transform (FFT). This method was employed as well as it is usually adopted in current HRV analysis as suggested by the European (Cardiac) Task Force in 1999. For five minutes recorded tachogram, the FFT method enabled us to identify the three bands of interest in the frequency domain. The VLF band ranging from 0.003 Hz to 0.04 Hz relates mainly thermoregulation, hormonal activity and renin-angiotensin system, the low frequency band (LF), is ranging from 0.04 Hz to 0.15 Hz, and relates mainly sympathetic activity and the high frequency (HF) band ranging from 0.15 Hz to 0.40 Hz and relating vagal activity. The physiological explanation of the VLF component of the HRV is uncertain. As said, it seems to relate thermoregulation, renin-angiotensin system, and hormonal contributions. The LF component is correlated with sympathetic and parasympathetic modulation, whereas parasympathetic activity is considered the dominant contributor to HF power. In addition for each subject the mean HR, the standard deviation of N-N (normal beats), and the total Variability were estimated. Soon after the initial recording of the tachogram at rest condition, the BWE section of therapy started. Each subject was submitted to Brain Entrainment using the mp3 neuro programmer software available on line at the web site http://www.transparentcorp.com/products/n p/. Being the first session of therapy, it was extended only for twenty minutes. Simultaneously his /her tachogram activity was on line monitored, recorded and elaborated.

The results were analyzed by using proper software for estimation of heart frequency (HR), the variability of the R-R intervals in the domain of the frequency (HRV), the VLF band in the Fourier spectrum that seems to relate thermoregulation, hormonal activity and renin-angiotensin system, the LF band that is so called to identify in particular the sympathetic activity of the ANS system, and finally the HF band that relates instead the activity of the parasympathetic activity of the ANS.

The scheme of the treatment was that we used alpha-stimulation employed to alleviate anxiety and stress issues. This therapeutic scheme also included the technique of the dissociation which is particularly useful for subjects with restless and trouble relaxing. The duration of each session was established to be 20 minutes being the first experience of brain entrainment for each subject.

Results

Let us start evidencing the ranges that we usually use in HRV analysis in our country. They arise from our previous experimentation performed on about one thousand normal subjects differentiated in two class age. The young subjects with age ranging from 25 to 45 years and the old subjects with age ranging from 45 to 70 years.

For the group of normal young subjects we fix the following values: Mean HR (59-96 BPM). Standard deviation of normal N-N beats (40-100 msec), Logarithmic value of Total Power (6.9-9.1 corresponding to range 992.27-8955.29 in PSD. PSD means Power Spectral Density and relates directly the total variability of the starting R-R signal. VLF Power (5.4-7.1, corresponding to the range 221.40-1211.96 in PSD), LF Power (6.3-8.4) (544.57-4447.06 in PSD), HF Power (5.1-7.3) (164.02-1480.30 in PSD).

The first subject, S.L., female, 30 years old, started with the following values: 89.2 BPM, 36.9 msec as standard deviation, 7.22 as Total Power (1366 ), 6.06 as VLF Power (430), 6.14 as LF Power(465) and 5.00 as HF Power (150) with LF/HF= 3.10. The subject thus showed a decreased variability in HR (standard deviation) and a decreased value in the HF-vagal band. After the 20 minutes session of BWE her values were the following: 81.1 BPM, 42.3 msec as standard deviation, (she reached the normal value), 7.49 as Total Power (1797) (she reached the normal value), 6.4 as VLF Power (602), 6.38 as LF power (591) and 6.25 (518) as HF Power (she reached a very satisfactory normal value), LF/HF= 1.14. We had a reduction of about 10% in the BPM, an increase of standard deviation about 14% (increased heart rate variability), an increased 31% in total Power variability, an increase 40% value for the VLF Power, an increased value about 27% in LF Power and an increase about 245% in vagal HF Power. In brief, the alfa stimulation induced in the subject an improvement in the total variability and a very
important improvement in parasympathetic activity.

The second subject, S.R., man, 50 years old, started with the following values: 95.7 BPM, 15.9 msec as standard deviation, 5.23 as Total Power (253), 4.06 as VLF Power (58), 4.34 as LF Power (77) and 4.39 as HF Power (81) and LF/HF=0.95. The subject thus showed a decreased variability in HR and decreased values in Total Power, LF and HF power. After the 20 minutes session of BWE his values were the following: 87.1 BPM, 20.1 msec as standard deviation, 6 as Total Power (407), 4.62 as VLF Power (102), 4.56 as LF power (96) and 5.09 as HF Power (162), LF/HF=0.59.

We had a reduction of about 10% in the BPM, an increase of standard deviation about 26% (increased heart rate variability), an increase about 60% in total Power variability, an increase about 75% for the VLF, 24% for LF Power and an increase about 100% in vagal HF Power with a final value of 5.09 almost to reach the range of the normal values for young subjects, (5.1-7.31). In brief, also in this case the alfa stimulation induced in the subject an improvement in the total variability and in parasympathetic activity.

The third subject, S.P., female, 35 years old, started with the following values: 91.9 BPM, 28.6 msec as standard deviation, 6.7 as Total Power (820), 4.71 as VLF Power (111), 6.15 as LF Power (471) and 5.2 as HF Power (183), LF/HF= 2.57. The subject thus showed a decreased variability in HR but she was in rather almost accordance with the range of the normal values for Total Power, LF and HF powers. She also evidenced unbalancing in LF/HF ratio. It follows that this is a case of greater interest in order to investigate as BWE acted. After the 20 minutes session of BWE her values were the following: 83.2 BPM, 34.8 msec as standard deviation, 7.1 as Total Power (1212), 5.48 as VLF Power (240), 6.34 as LF power(570) and 5.69 as HF Power(297), LF/HF=1.92. We had a reduction of about 10% in the BPM, an increase of standard deviation about 22%, an increase about 48% in total Power variability, an increase about 116% in VLF Power an increase about 21% for LF Power and an increase about 62% vagal HF Power. In brief, also in this case the alfa stimulation induced in the subject a large improvement in the total variability.

The fourth subject, S.Sc., female, 28 years old, started with the following values: 92.1 BPM, 24.9 msec as standard deviation, 6.43 as Total Power (623), 5.66 as VLF Power (288), 5.50 as LF Power (245) and 3.9 as HF Power (50) with an unbalanced ratio LF/HF=4.90. After the 20 minutes session of BWE her values were the following: 89.1 BPM, 27.9 msec as standard deviation, 6.65 as Total Power (779), 5.23 as VLF Power (187), 6.06 as LF power (431) and 4.71 as HF Power (112), LF/HF=3.85. We had a reduction of about 4% in the BPM, an increase of standard deviation about 12%, an increase in Total Power about 25%, a decrease about 35% for VLF, increase about 76 % LF and an increase about 124% for vagal HF Power. In brief, also in this case the alfa stimulation induced in the subject a dominant improvement in the total variability and parasympathetic activity.

The fifth subject, A.L, female, 30 years old, started with the following values: 95.1 BPM, 29.6 msec as standard deviation, 6.77 as Total Power (876), 4.48 as VLF Power (89), 5.69 as LF Power (296) and 5.98 as HF Power (396) and LF/HF=0.74. The subject thus showed a decreased variability in HR and decreased values in Total Power, LF and HF power. After the 20 minutes session of BWE her values were the following: 89.8 BPM, 41.8 msec as standard deviation, 7.46 as Total Power (1750), 4.29 as VLF Power (73), 6.52 as LF power (679) and 6.81 as HF Power (906), LF/HF=0.74.

We had a reduction of about 10% in the BPM, an increase of standard deviation about 26% (increased heart rate variability), an increase about 60% in total Power variability, an increase about 75% for the VLF, 24% for LF Power and an increase about 100% in vagal HF Power. After the 20 minutes session of BWE her values were the following: 89.1 BPM, 27.9 msec as standard deviation, 6.65 as Total Power (779), 5.23 as VLF Power (187), 6.06 as LF power (431) and 4.71 as HF Power (112), LF/HF=3.85. We had a reduction of about 4% in the BPM, an increase of standard deviation about 12%, an increase in Total Power about 25%, a decrease about 35% for VLF, increase about 76 % LF and an increase about 124% for vagal HF Power. In brief, also in this case the alfa stimulation induced in the subject a dominant improvement in the total variability and parasympathetic activity.

The results are summarized in Tables 1 and 2.

Discussion
In conclusion, we may say that in the examined subjects we had an increase in standard deviation varying from 12% to 20%, an increase in Total Variability ranging from 25% to 60%, an increase in VLF variability
ranging from 40% to 116%, (with an only one decreasing value of 35%), an increase in LF ranging from 21% to 76% and an increase in HF ranging from 62% to 245%. These are very promising results in spite of the small sample of examined subjects.

Table 1

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Table 2: PSD values

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Obviously, we must take in consideration that FFT gives only a linear analysis of data when non-linear basic mechanisms are involved in R-R modulation by ANS. Consequently, we expect more complete evidences by adding to the previously FFT analysis also more advanced non-linear methods that we have introduced in literature as the CZF and CKZF (Conte et al., 2009). CZF and CKZF are abbreviations to characterize such new nonlinear methods of investigation that were introduced by us. The results, extended also to a more articulated sample of experimentation, are in progress.

However, it seems that a conclusion is possible at this time. Alfa rhythm during BWE interacts with the brain stem control in the different HRV bands taken in consideration. We could hypothesize different patterns but in our perspective we retain that the limbic system is the most appropriate to be considered.

References


