CARDIAC RHYTHM REFLECTS MENTAL CONDITION AS CONFIRMED BY DETRENDED FLUCTUATION ANALYSIS AND SUBJECTIVE ASSESMENT METHOD

Albert M. Hutapea
Applied Technology Lab, Biological Science, Universitas Advent Indonesia, Parongpong
Bandung Barat 40559, Indonesia
amhutapea@unai.edu

and

Toru Yazawa
Biophysical Cardiology Research, Neurobiology, Biological Science, Tokyo Metropolitan University,
Hachioji, Tokyo, Japan
yazawa-tohru@tmu.ac.jp

ABSTRACT

Work-related mental stress increases cardiovascular morbidity and mortality. This health problem is extensively studied and is assessed by both subjective and objective methods. Detrended fluctuation analysis (DFA) has been proposed as a potentially useful objective method to quantitatively determine the signs of cardiovascular disorders. Medical personnel, healthy and ill subjects can all benefit from a DFA of cardiac rhythm in detecting the presence and determining the degree of mental stress. Results from this study describe that all of the top and middle management personnel have low scaling exponent and most of them confirmed to be experiencing stress, in contrast with the common employees who exhibited an exponent of 1 and believe that they have a enjoyable life every day. In this study, the finding of the DFA of cardiac rhythm (objective method) agrees with the finding of the stress level questionnaire (subjective method).

Keywords: detrended fluctuation analysis, work-related mental stress, cardiacc rhythm, scaling exponent.

INTRODUCTION

The general effects of mental stress on health have been extensively studied and are thus well understood. Mental stress affects the physiological condition of the heart e.g. rhythm because there is a strong connection between the brain and the heart. Stress assessment may help individuals better understand their stress level and provide physicians with more reliable data for interventions.

Mental stress is difficult to manage because it cannot be measured in a consistent and timely way. Conventionally, subjective methods have been used to assess work stress. One popular subjective method used to characterize an individual's stress level is a structured interview or a questionnaire. This method provides only a momentary description of the individual's stress level because most individuals cannot accurately recall the history of their stress symptoms [1].

At present, the assesment of stress level is gradually shifting to considering the use of objective methods. It is recommendable that old subjective methods be supplemented with novel objective methods [2]. One objective method used to assess stress is analysis of heart rate variability (HRV), a technology that assess mental stress. This method has broad applications in clinical, workplace, sports and academic settings for stress detection and reduction as well as performance enchancement [3]. The other objective method is analysis of cardiac rhythm that assesses cardiovascular autonomic regulation and associations between psychological conditions and physiological reactions [4]. The usefulness of this method as an objective method in assessing mental stress is now being explored.

As a physiological response to stress, the increase in heart rate is mediated by the activation of the sympathetic nervous system and its dynamics is a product of an "autonomic balance" as a combination of the sympathetic and parasympathetic effects at cardiac tissue and the sinoatrial node [5]. There is strong experimental [6] and clinical evidence showing that alterations in the autonomic balance, best quantified by a reduction in baroreflex sensitivity, are strong predictors of sudden death during acute myocardial ischemia or after a myocardial infarction [7].

It is a well-established fact that mental stress and the emotions of everyday life can induce ventricular arrhythmias and sudden cardiac death that has been a major public health problem in many countries [8]. Research has shown that heart rhythm patterns is sensitive to changes in emotional state. Jouvien et. al. [9] reported that in most cases, sudden death is due to ventricular tachycardia or ventricular fibrillation complicating an ischaemic cardiac condition in adults. Thus it is imperative that individuals with high risk for this threatening health problem be identified and thus prevents and reduces degree of risk and decrease the death toll.

It is currently known that mental stress induces myocardial ischemia more common than previously noted [10] and mental stress-induced myocardial

ischemia is an independent predictor of cardiac death. Infact, coronary patients who exhibited reduced cardiac blood flow in response to a mental stressor, had triple risk of death during the next five years [11].

Clinical diagnoses and basic investigations are critically dependent on the ability to record and analyze physiological signals. Thus, we have studied the practical usefulness of Detrended Fluctuation Analysis (DFA) in analyzing the cardiac rhythm that represents the physiological condition of the heart. In our previous studies we found that DFA could distinguish the beating of intact hearts from isolated hearts [12]. From the results of this and our other studies we postulated that DFA is reliable and useful because it seems to reflect bodily physiological processes quite accurately.

In DFA studies an exponent value of 1 (see Table 1) has nonlinearly been determined to represent a healthy condition [13].

Table 1. Interpretation of the Exponent Value

Exponent	Meaning
0.5 - 0.899	Stress, PVC, alternans, naturally dying
0.9 - 1.199	Healthy, 1/f fluctuation
1.20 - 1.5	At risk of catastrophic circulation stoppage

This paper is a study of the "autonomic balance" by using the DFA of cardiac rhythm as the objective method for stress assesment and a conventional structured interview as the subjective method, as well as to study if the two methods complement each other. We present individual case studies instead of a statistical cohort investigation because we believe that there are no two individuals who are genetically identical. As has been pointed out in fields of preventive and curative medicine, tailored health interventions are more effective than the generic ones [14].

MATERIALS AND METHODS

Objective Method of Assessment

DFA of cardiac rhythm will be used as an objective tool to assess and quantify stress level among the subjects of the study.

Stable Baseline of the Recording. Cardiovascular variability is highly affected by changes in body posture and physical activiy [15]. The perturbation of the ECG signal due to physical activity is a major obstacle in applying this technology in real-world situations. However, we have overcome this problem by designing our own ECG amplifier that enabled us to obtain recording with a stable baseline.

Peak detection of the heartbeat. In order to ensure a perfect analysis of the peaks, we manually inspected and visually identified each one of the peaks of the heartbeats. We removed some peaks that have been identified as noises by manually screening the recording over the PC screen and included unidentifed peaks, thus avoiding missing true peaks. The visual identification of the peaks was also done to help determine premature ventricular contraction (PVC) as peak of a signal because the height of signal is sometimes very short (see Fig. 1), and in our previous study we found that even healthy-looking individuals may exhibit this arrhythmia [16].

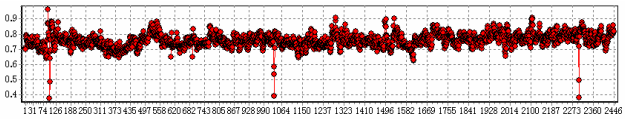


Figure 1. Three PVCs in a heart beat interval time series

Detrended Fluctuation Analysis (DFA). Although based on a relatively old idea conceived in 1980s [17], DFA has been proposed as a potentially useful method to identify the signs of cardiovascular disorders [18]. DFA has not yet been developed as a practical medical tool like electrocardiogram.

As has been described previously [17][19], the methods and computation of DFA is based on the concepts of "scaling" and "self-similarity." It can point to "critical" phenomena because systems near critical points exhibit self-similar fluctuations, which means that recorded signals and their magnified/contracted copies are statistically similar [18].

ECG recording. For ECG, three Ag-AgCl electrodes (+, -, and ground, Nihonkoden Co. Ltd. disposable Model Vitrode V) were used. Wires from ECG electrodes were connected to an amplifier of our own design. These ECG signals are then conveyed to a Power Lab System. During the recording, the subjects were seated comfortably and actively participated in a casual and friendly conversation with others and in the structured interview done by the researchers to obtain data on the personal lifestyle and relevant family history and on the subject's workplace conditions.

Subjective Method of Assessment

The subjective method of assesement was carried out using a validated eight-question questionnaire on work-related stress copyrighted by The Marlin Company, North Haven, CT and the American Institute of Stress, Yonkers, NY. The interview was a structured type and was carried out casually and informally during the recording. The score of the questionnaire is categorized into several level of stress (see Table 2).

Table 2. Interpretation of the Stress Score

Score	Degree of Stress
≤15	Low
16-20	Fairly Low
21-25	Moderate
26-30	High
31-40	Severe

Volunteers and Ethics

Subjects are owners, top and middle management personnel as well as ordinary personnel of business

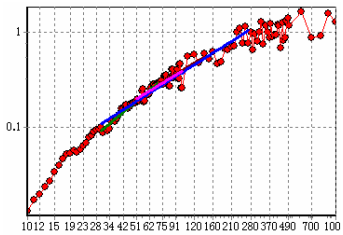
enterprises and educational institution in the cities of Bandung and Jakarta, Indonesia who volunteered to participate in our study. All subjects were treated as per the ethical control regulations of our respective universities, Universitas Advent Indonesia and Tokyo Metropolitan University.

RESULTS

Job stress is among the common type of chronic stress. All of the subjects of our study look healthy and happy, without exemption they all show a seemingly happy and normal life, shown by their kind and generous smiles. However, to our surprise they all fall into different category of cardiac health as determined by DFA of their cardiac rhythm. The outcome of our study shows that all individuals who are in managerial posts have low scaling exponent.

The mental stress that the subjects of this study experienced is manifested in the score of the structured interview done on them. In contrast with the low exponent value shown by the subjects occupying managerial positions, the ordinary employees, show high exponent value and they seem to have a "carefree" life as confirmed by the result of the structured interview (Table 3).

Case Study 1. Business Owner 1 (Male, 56 yo)

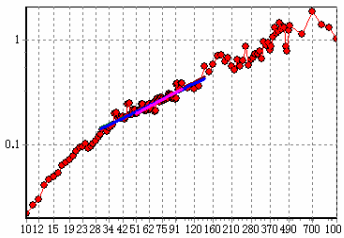


Box Size	Exponent
30-70	1.37
70-140	0.99
51-100	0.98
30-270	1.03

Figure 2. DFA results with the Business Owner 1.

The fitting from the box size 30-270 shows the best fitting; reflects characteristics of entire slope of the graph. The exponent is calculated to be 1.03 (Fig. 2), a good exponent showing that he has a steady physiological function of his nervo-cardiac interactions. The result of the structured interview shows that he has "fairly low" level of stress (Table 3).

Case Study 2. Business Owner 2 (Male, 42 yo)

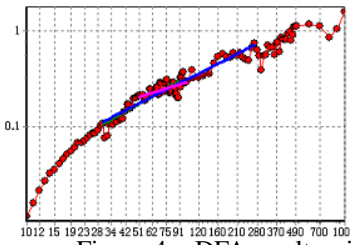


Box Size	Exponent
30-70	0.68
70-140	0.83
51-100	0.80
30-270	0.76

Figure 3. DFA results with the Business Owner 2.

DFA profile of Business Owner 2 shows that there is variation of exponent values in each box size. His exponent is a low 0.76 (Fig. 3). This shows an unsteady physiological functions of the subject in terms of nonlinear interactions between the heart and the autonomic nervous system.

Case Study 3. Top Manager 1 (Male, 56 yo)

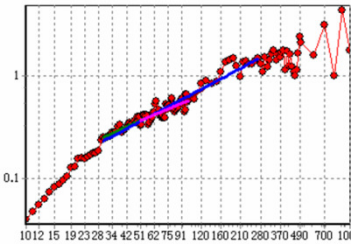


Box Size	Exponent
30-90	0.94
70-140	0.54
51-100	0.52
30-270	0.84

Figure 4. DFA results with the Top Manager 1.

We determined the Top Manager 1's scaling exponent to be 0.84. Figure 4 shows that plots do not show a beautiful straight line. Therefore, the scaling exponents calculated from different "box size" vary. We suspected that he was under stressful situations in his job which was confirmed by the structured interview (Table 3).

Case Study 4. Top Manager 2 (Female, 48 yo)

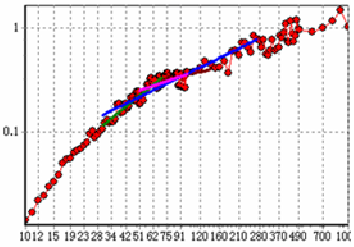


Box Size	Exponent
30-70	0.70
70- 140	0.98
51-100	0.66
30-270	0.84

Figure 5. DFA of the Top Manager 2.

From the DFA profile of the Top Manager 2 we determined an exponent of 0.84 (Fig.5). During the ECG recording we talked to her a lot and she mentioned that her job is stressful. The stress that she experienced as indicated by the low exponent is confirmed to be "high" level of stress by the result of the structured interview (Table 3).

Case Study 5. Middle Manager 1 (Male, 49 yo)



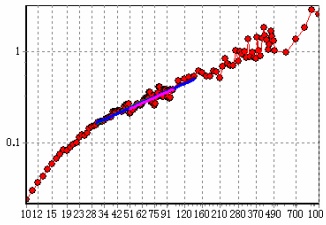
Box Size	Exponent
30-70	1.26
70-140	0.35
51-100	0.53
30-270	0.76

Figure 6. DFA of the Middle Manager 2.

From the DFA profile of the Middle Manager 1's fittings (Fig. 6) we conclude that is that his overall exponent is 0.76 and he apparently had stress and this was confirmed to be "high" level of stress by the result of the structured interview during our conversation (Table 3).

We can determine that his heart and its control system that is the autonomic nerve function are at least not working perfectly in terms of DFA.

Case Study 6. Middle Manager 2 (Male, 60 yo)

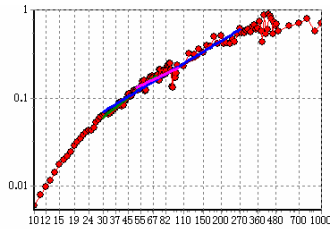


Box Size	Exponent
30-70	0.77
70-140	0.84
51-100	0.72
30-270	0.72

Figure 7. DFA profile of the Middle Manager 2.

The Scaling Exponent of the Middle Manager 2 (Fig. 7) is 0.72 and this is not a good value. His bodily system does not work perfectly under stressful job. Despite his happy look on the outside, his "high" stress level is shown by the result of the structured interview done on him (Table 3).

Case Study 7. Employee 1 (Male, 62 yo)

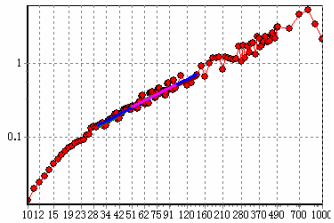


Box Size	Exponent
30-70	1.28
70-140	0.83
51-100	0.76
30-270	0.98

Figure 8. DFA profile Employee 1

The DFA (Fig. 8) of Employee 1 shows a scaling exponent of 0.98, and this is a normal value, which shows that he does not experience stress. He shows a care-free attitude toward life and he enjoys life. This is confirmed by the result of the structured interview to be "fairly low" level of stress (Table 3).

Case Study 8. Employee 2 (Female, 35 yo)



Box Size	Exponent
30-70	1.14
70-140	0.81
51-100	1.00
30-270	1.04

Figure 9. DFA profile of Employee 2

Scaling Exponent of Employee 2 (Fig. 9) is perfect at every box size. We conclude that her scaling is perfect in terms of cardiac health, this is exhibited by a straight line (exponent value of 1) in the slope of the plots. She smiles a lot. She talked actively about daily life to us and explained to us how much she was enjoying her life, and this is confirmed by the result of the structured interview to be "fairly low" level of stress (Table 3).

DISCUSSION

The results of both the subjective method and objective method of assessing stress are compared in the following table 3.

Table 3. Comparison: Stress Level and Exponent Value

Categories	Subjects	Stress Level	Exponent
Business Owner	1	Fairly Low	1.03 (Normal)
	2	High	0.72 (Low)
Top Management	1	High	0.84 (Low)
	2	High	0.84 (Low)
Middle Management	1	High	0.72 (Low)
	2	High	0.76 (Low)
Ordinary Employee	1	Fairly Low	1.00 (Normal)
	2	Fairly Low	0.98 (Normal)

Table 3 shows that different types of jobs induce different degrees of mental stress of the subjects. One's susceptibility to stress is also determined by his unique ability to cope with stress. For instance, table 3 also indicates that the subjects falling into the category of business owner show different results. One of them, a very well-established entrepreneur show a high exponent value. He is a mild-tempered person with a very calm deportment. The conclusion of the structured interview done on him show that he has little stress. The other subject on this category is a successful businessman. He is younger, mild-tempered and very friendly, too. However, he has a low exponent value compared with his counterpart. He is an open person and the result of the interview during the informal structured interview show that he is under job-related stress. Business Owner 1 seems to be able to cope better with the stress he encounters in his job compared with Business Owner 2.

Stress hormones (cathecolamines, including epinephrine) have damaging effects if the heart is exposed to their elevated levels for a long time. Stress can cause increased oxygen demand of the body, spasm of the coronary blood vessels and electrical instability in the heart's conduction system [20].

Heart rate measures the degree of autonomic cardiovascular activity especially the physiological aspect of emotions, whereas heart rate variability expresses the balance of the regulation of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) of the autonomic nervous system [4]. Wood reported that cardiac autonomic modulation during provocative stress shows similar physiological responses in both young and old adults [21].

Experience of negative emotions such as anger, frustration, or anxiety makes heart rhythms become more

erratic or disordered, indicating less syncronization in the reciprocal action between the SNS and PNS. In contrast, sustained positive emotions, such as appreciation, love, or compassion, are associated with a highly ordered or coherent pattern in the heart rhythms, reflecting a greater synchronization between the two branches of autonomic nervous system. The amount of heart rate variability is found to remain virtually the same during the two emotional states; however, the pattern of the heart rhythm changes distinctly [3].

Our study shows that the stress experienced by our subjects who hold administrative position is confirmed by their low scaling exponent as calculated by DFA. The low scaling exponent exhibited by the subjects may be caused by the presence of cardiac arrythmia, because our previous study shows that arrythmia lowers the scaling exponent [22].

Although in many cases arrhythmia induction is mediated by myocardial ischemia [23], mental stress and emotions also can be arrhythmogenic without inducing demonstrable ischemia, even in coronary artery disease patients [24]. It was reported that acute emotional arousal can trigger life-threatening arrhythmias [25] and myocardial ischemia [26]. The exact mechanism by which sympathetic activity induced by mental stress triggers or facilitates ventricular arrhythmias in the absence of ischemia is not clear.

Novel Devise to Check Cardiac Rhythm

It has been a talk over many years that there is a need to expand nonlinear cardiac rhythm analysis from conceptual level to an actual design and production of a novel devise that implements the concept. As a response to this challenge, we created customized software that we utilized to investigate cardiac rhythms of hundreds of seemingly healthy and unhealthy subjects. Interpretation of the scaling exponent was referred to a value of scales formulated by Kobayashi and Musha (Table 1) [13]. A value of 1 has been set to indicate healthy condition, and other than 1 indicates unhealthy condition. The value of 1 as an indication of healthy condition was first confirmed by our group in animal experiments [12]. We are convinced that this diagnostic strategy would be useful for engineering work in the future because it is quantitative and therefore reliable. It was through these series of investigations that we found that the theory could be applied to human hearts [27]. Using this theory in ECG recordings, we were able to measure a state of "deep sleep" [28] as well as the heart conditions of exercising athletes at an olympic training center [16].

As shown in this article, we discovered that mental stress contribute to the low scaling exponent. Our idea of DFA-based health monitoring is geared toward preventive medicine. We cannot hope to improve public health without a shift in emphasis from curative treatments to early detection and prevention of diseases [22].

Concluding Remarks

Mental stress lowers the scaling exponent. Our temporary guideline for determining the wellness of the heart by the scaling exponent is that a value near 1.0 (specifically, 0.90 - 1.19) is healthy.

We thereby have hope that DFA can quantitatively assess the state of health reflected by the degree of cardiac wellness. DFA appeared to reflect not only the condition of the heart itself but also its physiological interaction with the nervous system. We propose that DFA be used as a tool to detect the onset of cardiac problems, including disorders of the autonomic nervous system.

REFERENCES

[1]. N Breslau, R Kessler, EL Perterson Post-traumatic stress disorder assessment with a structured interview: reliability and concordance with a standardized clinical interview. **International Journal of Methods in Psychiatric Research**, 7(3):121-127, 1998.

[2]. R Orsila, M Virtanen, T Lookkaala, M Tarvainen, P Karjalainen, J Viik, M Savinainen, CH Nygard Perceived Mental Stress and Reactions in Heart Rate Variability – a pilot study among employees of an electronics company. **International Journal of Occupational Safety and Ergonomics** 2008;3(14):275-283.

[3]. R McCraty, D Tomasino, Heart Rhythm Coherence Feedback: a new tool for stress reduction, rehabilitation and performance enhancement. **Proceedings of the First Baltic Forum on Neuronal Regulation and Biofeedback**, 2004.

[4]. T Heponiemi, N Ravaja, M Elovainio, P Naataned, L Keltinangal-Jarvinen. Experiencing positive and negative effect during stress: relationships to cardiac reactivity and to facial expressions. **Scandinavian Journal of Psychology** 2006;47(5):327-32.

[5]. X Jouven, PJ Schwatrz, S Escolano, C Straczek, M Tafflet, M Desnos, JP Empana and P Ducimetiere, "Excessive heart increase during mild mental stress inpreparation for exercise predicts sudden death in the general population'', **European Heart Journal Vol.** 30, 2009, pp.1703-1710.

[6]. PJ Schwartz, MT La Rovere, E Vanoli, " Autonomic nervous system and sudden cardiac death. Experimental basis and clinical observations for post-myocardial infarction risk stratification", **Circulation,** Vol. 85, 1992, pp. I77–I91.

[7]. GM De Ferrari, A Sanzo, A Bertoletti, G Specchia, E Vanoli, PJ Schwartz, "Baroreflex sensitivity predicts long-term cardiovascular mortality after myocardial infarction even in patients with preserved left ventricular function", **Journal of American College of Cardiology** Vol. 50, 2007, pp. 2285–2290.

[8]. H Hemingway, M Malik, M Marmot, "Social and Psychosocial Influences on sudden cardiac death, and ventricular arrhythmia and cardiac autonomic function", **European Heart Journal**, Vol. 22, 2001, pp. 1082–101.

[9]. X Jouven, PJ Schwatz, S Secolano, C Straczek, M Tafflet, M Desnos, PJ Empana, P Ducimetiere, 'Excessive heart rate increase suring mild mental stress in preparation for exercise predicts death in the general

population'', **European Heart Journal,** Vol. 30, 2009, pp.1703-1710.

[10]. A Doorey, B Denenberg, V Sagar, T Hanna, J Newman, PH Stone . "Comparison of myocardial ischemia during intense mental stress using flight simulation in airline pilots with coronary artery disease to that produced with conventional mental and treadmill exercise stress testing", **Journal of American College of Cardiology,** Vol. 108, No. 5, 2011, pp. 651-7.

[11]. DS Sheps, R Soufer, KE Freedland, "Psychological Stress and Myocardial Ischemia: understanding the link and the implications", **Psychosomatic Medicine,** Vol. 69, 2007, pp. 491-492

[12]. T Yazawa, K Kiyono, K Tanaka, and T Katsuyama, "Neurodynamical control systems of the heart of Japanese spiny lobster, Panulirus japonicus", **Izvestiya VUZ Applied Nonlinear Dynamics,** Vol. 12, No. 1-2, 2004, pp. 114-121.

[13]. M Kobayashi and T Musha, "1/f fluctuation of heartbeat period." **IEEE Transactions on Biomedical Engineering**, Vol. 29, 1982, pp. 456-457.

[14]. YJJ van der Veen, O de Zwart, J Mackenbach, JH Richardus. Cultural tailoring for the promotion of Hepatitis B screening in Turkish Dutch: a protocol for a randomized controlled trial. **BMC Public Health** 2010;10:674

[15]. H van Steenis, J Tulen. The effects of physical activities on cardiovascular variability in ambulatory situations. Engineering in Medicine an Biology Society, 1977. **Proceedings of the 19th Annual International Conference of the IDDD**, 1:105-108, Nov. 1997.

[16]. Y Toru, AM Hutapea, Y Shimoda, "Quantification of Athlete's Heartbeats Engaged in Ergometer Exercise: A Detrended Fluctuation Analysis Study Checking the Heart Condition. Lecture Notes on Engineering and Computer Science**University of California Berkeley,** ", 2011, pp. 585-590

[17]. CK Peng, S Havlin, HE Stanley, and AL Goldberger, "Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series", **Chaos**, Vol. 5, 1995, pp. 82-87.

[18]. HE Stanley, LAN Amaral, A L Goldberger, S Havlin, P Ch Ivanov, and CK Peng, "Statistical physics and physiology: monofractal and multifractal approaches", **Physica A**, Vol. 270, 1999, pp. 309-324.

[19]. O Barquero-Perez, JM de Sa, JL Rojo-Alvarez, and R Goya-Esteban, "Changes in detrended fluctuation indices with aging in healthy and congestive heart failure subjects". **Computers in Cardiology**, Vol. 35, 2008, pp. 45-48.

[20]. JM Torpy. Chronic Stress and the Heart. Journal of **American Medical Association** 2007;298(14):1722.

[21]. R Wood, B Maraj, MC Lee, R Reyes. Short-term heart rate variability during cognitive challenge in young and older adults. **Age Ageing** 2002;31(2):131-5.

[22]. T Yazawa, AM Hutapea, T Katsuyama, Y Shimoda, "Scaling exponent during arrythmia: detrended fluctuation analysis is a beneficial biomedical computation tool. **Proceedings of the ASME 2011 International Mechanical Engineering Congress & Expostion IMECE 2011** (in press).

[23]. PH Stone, DS Krantz, RP McMahon, AD Goldberg, LC Becker, BR Chaitman, HA Taylor, JD Cohen, KE Freedland, BD Bertolet, C Coughlan, CJ Pepine, PG Kaufmann, DS Sheps, "Relationship among mental stress induced ischemia and ischemia during daily life and during exercise", **The Psychophysiologic Investigations of myocardial ischemia (PIMI) study. J Am Coll Cardiol,** Vol. 33, 1999, pp. 1476–84.

[24]. R Lampert, D Jain, MM Burg, WP Batsford, CA McPherson, "Destabilising effect of mental stress on ventricular arrhythmias in patients with implantable cardioverter-defibrillators". **Circulation**, Vol. 10, 2000, pp. 158–64.

[25]. R Lampert, T Joska, MM Burg. Emotional and Physical Precipitants of Ventricular Arrhythmia. **Circulation** 2002;106:1800-5.

[26]. DS Sheps, RP McMahon, L Becker. Mental Stress-induced Ischemia and All-cause Mortality in Patients with Coronary Artery Disease: results from the psychophysiological invertigations of myocardial ischemia study. **Circulation** 2002;105:1780-4.

[27]. T Yazawa, K Tanaka, and T Katsuyama, "DFA on Cardiac Rhythm: Fluctuation of the heartbeat interval contain useful information for the risk of mortality in both, animal models and humans," **(WMSCI 2006). Proceedings** Vol. 1, pp. 212-217.

[28]. T Yazawa, Y Shimoda, and AM Hutapea (2011), "Evaluation of sleep by detrended fluctuation analysis of the heartbeat, **IAENG Transactions on Engineering Technologies**, 6, in AIP Conference Proceedings series, the congress WCECS 2010", AIP press, USA.