Quantifying Stress Using mDFA: Heartbeats Exhibit Stress/Fear/Anxiety in Animal Model and Humans

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ABSTRACT

"Stress" has not been fully defined in terms of neuroscience. But, it might be possible to quantify it, like body temperature. The aim of this study was to develop a method to quantify stress, fear and anxiety that has not been accomplished. In the present study, we present a method to quantify them using the biomedical vital information, i.e., the timing of heartbeat. Here electrocardiograms of both animal models and humans were analyzed by modified detrended fluctuation analysis (mDFA), which calculates a scaling exponent (SI) from the heartbeat interval time series. The SI was able to numerically distinguish between normal and abnormal hearts. SI values varied with heart conditions, i.e., healthy basal or stressful conditions. This study suggests that mDFA has potential as a practical method for the construction of a device for health management.

Keywords: Heartbeat, mDFA, Quantifying stress, Scaling exponent.

1. INTRODUCTION

Cardiac nerves—comprising accelerator nerves (CA) and inhibitory nerves (CI)—govern the activity of the heart. These autonomic nerves transmit psychological messages to the heart; indeed, they continuously modulate heart rate and force of heart contractions. Thus, the heart is a reflection of neural activity. While cardiac nerve activity is not clearly understood because it is difficult to record, it has been successfully recorded in crustaceans, by Field and Larimer in 1975 [1], Young in 1978, and Yazawa [3, 4]. In those experiments, both CA and CI were active when the heart was beating. Interestingly, CI were frequently excited at a high rate, and concomitantly, CA were momentarily quiet [4]. During this period, the heartbeat disappeared, although a rapid restitution occurred shortly thereafter. The brief cessation of heartbeat occurred regularly and intermittently if an animal was under "stress-free" conditions: for example, hiding in a shelter. The stress-free behavior was not observed if humans were in close proximity to the lobster and crab. Crustaceans are incredible specimens because their stress can be determined using electrocardiograms (EKGs).

Footnote: This article is an update of the article already presented, for IMCIC2015 in March, Orlando, FL, USA. This WMSCI article is a different perspective of what I have already presented.

Crustacean and human hearts strongly resemble each other in structure and function, that is to say, both have a blood-circulation-pump and its controller unit, the autonomic cardiac center in the brain. It is known that homologous genes (e.g., Nkx2-5, the NK2 homeobox gene) function to form the developing heart of all animals [5]. In crustaceans and humans, both CA and CI connect with the cardiac pacemaker cells, but CA further proceed to the ventricular muscles beyond the pacemaker cells. Why do CA control the entire heart? The answer is that CA–muscle connections can implement direct modulation of contractile force, whereas CI merely suppress rhythm [6]. The resemblance between crustacean and human hearts indicates that some knowledge obtained from crustacean hearts should be applicable to human hearts.

I studied EKGs of both animal models and humans and used modified detrended fluctuation analysis (mDFA) [7] to calculate the scaling exponent (SI) (see Peng et al., [8]). SI was able to numerically distinguish between normal and abnormal hearts. Here, the potential application of mDFA as a viable method for assessing health status is presented.

2. MATERIALS AND METHODS

Heartbeats were recorded electro-physiologically using a PowerLab system (ADInstruments, Australia) from crabs, lobsters, and humans. A set of three, ready-made Ag–AgCl electrodes (Vitrode V, Nihonkoden Co. Ltd. Tokyo) were used for human EKG monitoring. EKG signals were transferred to the PowerLab system, as were finger pulse recordings. Permanently mounted metal electrodes were glued on the crustacean carapace for EKG recordings. The metal electrodes were prepared as a plated metallic pin or a stainless-steel bolt 1-2 mm in diameter of bolt axis. All subjects were treated according to the ethical regulations of Tokyo Metropolitan University.

3. RESULTS

Animal models

Figure 1 shows an example of crustacean heartbeat recording. The spiny lobster (*Panulirus japonicus*) exhibited a periodic slowdown in heart rate when the specimen was at rest, i.e., without stressful stimuli from the environment. Crabs under relaxed conditions also exhibit this on/off pattern, i.e., alternating appearance of a high heart rate (50–70 beat per min (BPM) with extremely low rates (5–15 BPM) (data not shown). Both conditions were analyzed for various time periods (Figure 2). The results lead me to propose that mDFA is practical for monitoring human hearts as well.

Human subjects

Human EKGs were analyzed using the same mDFA methodology. I recorded all subjects EKGs by myself at seated position for 30 to 50 min with interviewing about subject's daily life, stress, medical history, and family history. Table 1 shows SI differences between stressed and non-stressed individuals. The appendix in Table 1 shows that cardiac muscle injury can be detected using mDFA.

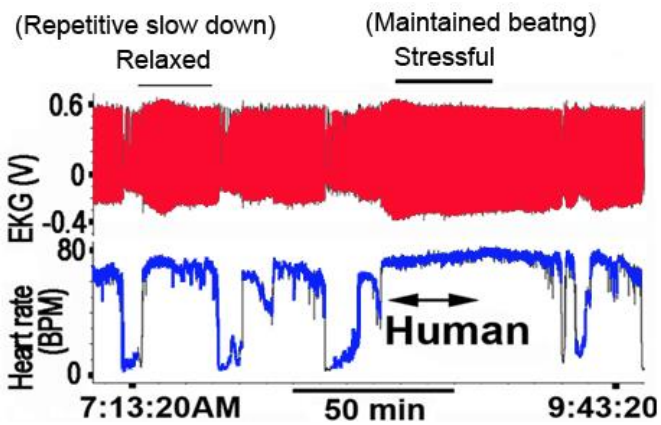

Figure 1. Japanese spiny lobster (*Panulirus japonicus*) EKG. Black bars represent the relaxed (thin bar) or stressed (thick bar) condition. Arrows indicate human presence for lobster feeding.

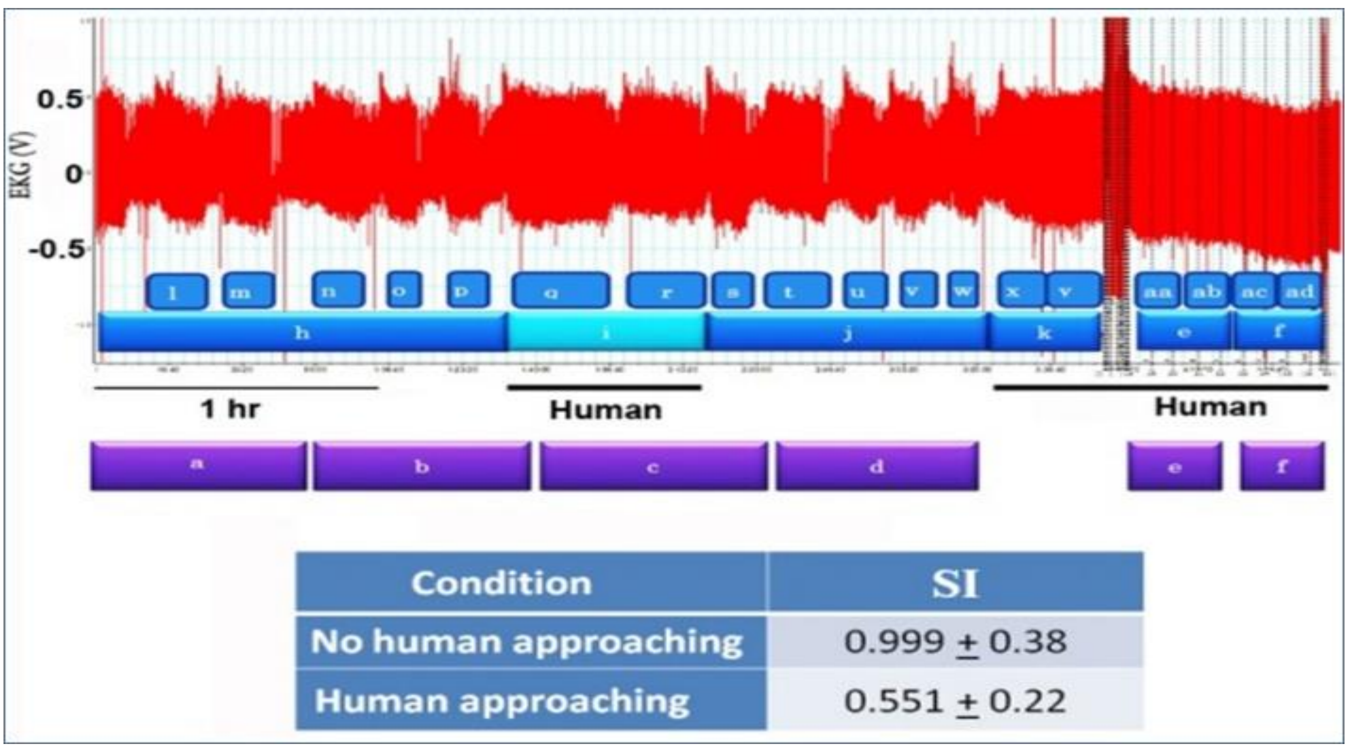

Figure 2. Scaling exponent (SI) computed from EKGs under relaxed and stressed conditions. Note, steady beating continued under the stressed condition. This was the consequence of discharge of cardio-regulatory nerves, i.e., increased cardio-accelerator activity and concomitant inhibitor cessation. This autonomic response is the lobster's expression of stress/fear/anxiety.

4. DISCUSSION

While I have not extensively studied thousands of human subjects (Table 1), people who have stress and conduct top management seem to have quantifiable degree of stress. Fundamental idea of the quantification was derived from animal experiments (Figure 2). Cardiovascular system in various animals would be controlled under the same law, in terms of evolution of life on earth. The law is the scaling law of heartbeat time series. This study suggests that the scaling exponents can quantify stress.

5. CONCLUSION

mDFA and SI provide useful information. The findings suggest mDFA can be incorporated into a device for checking health and stress levels (Figure 3).

Table 1. Comparizon: Stress level and exponent value (Indonesia, 2012, working with Prof. A. Hutapea)

Categories	Age	Stress leel (Interview)	SI
Business owner (a company) No. 1	50s, Male	Fairly low	1.03
Business owner (a company) No. 2	50s, Male	High	0.72
Top management, President of a Univ.	60s, Male	High	0.84
Top management, Vice President of a Univ.	40s, Female	High	0.84
Middle management, Dean	40s, Male	High	0.72
Middle management, Secretary of president	40s, Female	High	0.76
Ordinary employee, Teaching only professor, No. 1	50s, Male	Fairly low	1
Ordinary employee, Teaching only professor, No. 2	50s, Female	Fairly low	0.98
Table 1. Appendix: Cardiac disease	Age	Daily life	SI
Patient with stent-placement	60, Male	OK	1.26
Patient with bypass-surgery	45, Male	OK	1.38
Patient with inplantable cardioverter	53, Male	OK	1.22
Ventricular septal defect (20 y ago operation)	48, Female	OK	1.41
Healthy representative, housewife	46, Female	OK	1.03

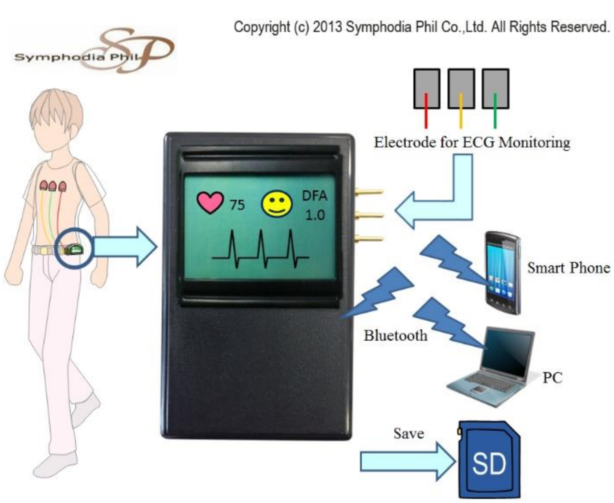

Figure 3. A prototype device already working.

Acknowledgements

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9. REFERENCES

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