Anxiety, Worry and Fear: Quantifying the Mind Using EKG Time Series Analysis

Toru Yazawa

Additional information is available at the end of the chapter

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Abstract

We analyse the heartbeat interval time series in this chapter. Our time series analysis concepts and techniques have been reported previously, for example, in the Intech Book chapter. Here, we would like to introduce how it works by presenting typical examples. The techniques can distinguish between healthy, sick and stressful hearts. All data were obtained by us from natural heartbeat data. Therefore, we have notes behind data, especially about behavioural psychological observations. Results of analysis are the following: healthy hearts exhibit a healthy scaling exponent (SI), which is near 1.0, stressful hearts exhibit a lower SI, such as 0.7, dying heart's SI approaches to 0.5, and so forth.

Keywords: cardiovascular system, EKG, electrocardiogram, heartbeat-interval time series, modified detrended fluctuation analysis, mDFA, scaling exponent

1. Introduction

The cardiovascular control system (CVCS) – the heart, the vessels and the brain – executes optimum performance of the blood circulation if it works under a healthy condition. If CVCS is defective, the heart contractions lose any useful rhythm, for example, like as patient who is suffering from sinus node dysfunction. It is ideal to identify the causes of defectiveness by existing diagnostic methods.

The discovery of the circulation of the blood (William Harvey in 1628) was a long time ago. But until recently, we do not know about what is the proper behaviour of CVCS. In 1982, Kobayashi and Musha reported and determined that a healthy heart exhibits a 1/f spectrum-like fluctuation [1]. 1/f fluctuations are widely found in nature (beginning, Johnson and Nyquist noise, 1920s). Until now, 1/f rhythm of healthy hearts has become a widely held notion [2, 3]. We consider that 1/f spectrum is a state where, mathematically, scaling exponent (SI) is 1.0. We have, therefore, made a time series analysis programme in order to check the heartbeat wellness: computing whether or not a time series exhibits SI = 1.0. Our technique is a random-walk analysis, which calculates 'the number of steps proceeded within a box, i.e., increased or decreased' [4, 5]. The name of the method is mDFA (abbreviated name, modified detrended fluctuation analysis). We have explained it elsewhere, about the box, steps and entrance and the exit of a box, and so on [4, 5]. As a result, our method showed that SI can quantify the condition of CVCS [4, 5]. This quantification is like the thermometer. It has a baseline value. If the body condition is normal, it is 37°.

In particular, as far as we know, the association of high SI with unpredictable cessation of heart pumping has been discovered. It has not been shown empirically before us. We first observed it in the crustacean heart; thereafter, we confirmed the same phenomena (high SI) on humans with ischaemic disease and a person who underwent a surgery that made an incision of the heart [4, 5].

By the way, our heart rhythm is apparently not regular. Cardiac rhythmicity is continuously changing, because CVCS is responding to stimulus from the internal and outer world. Therefore, marked irregularity and/or over-regularity might be a deficient state. At least mDFA seems to detect defect/problem that derives from an injury of the myocardial cells caused by either ischaemic reasons or artificial/synthetic reasons. It seems that mDFA is a better way to compute this correlation between an SI value and a poor condition of CVCS.

Lower animals such as crustaceans have a heart. Crustacean CVCS has been well studied over 100 years. For example, the English comparative biologist-anatomist Tomas Henry Huxley published about crayfish zoology in ca. 1900s [6]. And Swedish American physiologist Anton Julius Carlson has already documented detailed morphology and physiology of the heart of horseshoe crabs (*Limulus polyphemus*), in 1904 [7]. It is worth noting that Carlson already considered invertebrate hearts as a model of our heart.

Until now, the anatomy of cardiac nerve of crustaceans is well documented. The crustacean animal has autonomic nervous system that controls the heart (see Cooper et al., e.g. [8], and legendary articles [9, 10]). Typically, crustacean heart is innervated by two acceleratory nerves and one inhibitory nerve (**Figure 1**, see [11]). **Figure 2** shows a diagrammatical view of cardiac nerves in both vertebrates and crustaceans. Crustacean diagram is based on our publication [11]. In summary, the cardiac inhibitory nerve innervates pacemaker cells (P in **Figure 2**) in both crustaceans and humans. In turn, the cardiac acceleratory nerve innervates not only P cells but also myocardial cells (ventricle cells). As shown in **Figure 2**, it is important to acknowledge that nerve fibres of accelerator (CA) proceed deep inside the heart. This fact presents evidence that CA nerve regulates not only the rhythm of the heart but also the strength of heart contraction. **Figure 2** highlights an important issue in terms of evolution: the heart and its controller system resemble in both invertebrate and vertebrate. Further discussions about the resemblance are shown in Ref. [4]. Thus, we strongly expect that a basic finding obtained from invertebrate animals is applicable to humans, according to an evolutional view [4].

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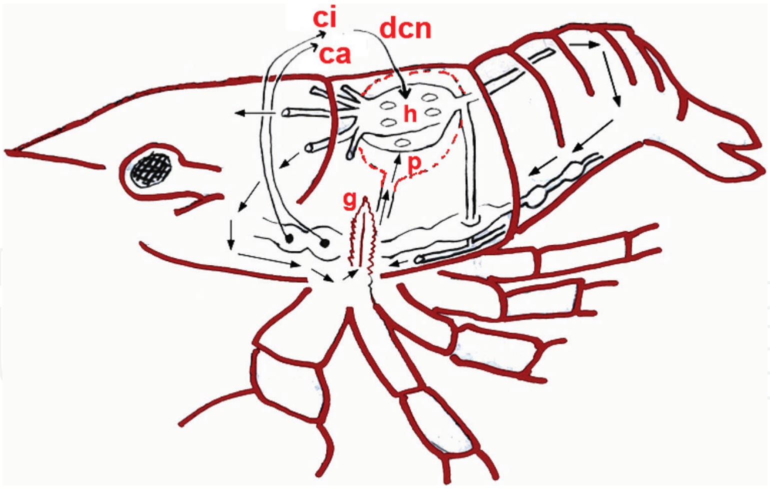


Figure 1. Crustacean CVCS. Autonomic-like regulation of the heart. Cardio-regulatory nerves are the following: ci, cardio-inhibitory nerve, ca, cardio-acceleratory nerve, dcn, bilateral dorsal cardiac nerves. A dcn carries only three nerve axons, one ci and two ca nerves. Arrows, the direction of blood flow. Blood is pumped out from the heart (h), all meeting at the gill (g) where blood is oxygenated. After leaving from the gill, blood enters the pericardial sinus (p) and finally withdrawn into the heart through ostium. Therefore, this is a system constituted of a pump and a controller.

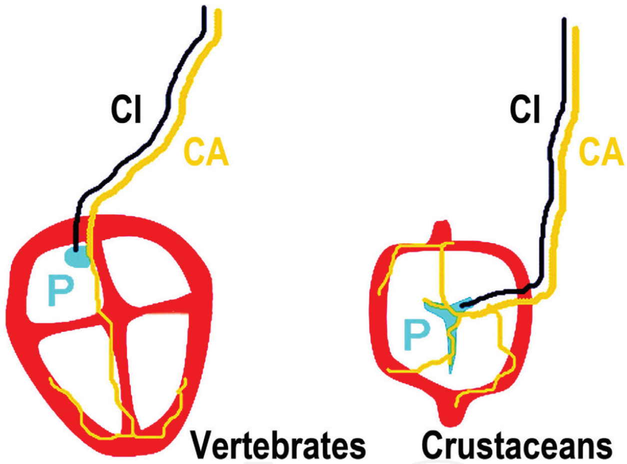


Figure 2. Resemblance of a wiring design in CVCSs between evolutionarily distinct two different animals, vertebrates (four chambered) and crustaceans (single chambered). The cardioinhibitory (CI) and cardioacceleratory (CA) nerves, P, pacemaker cells.

2. EKG: crustaceans

Therefore, we have been studied crustacean heart as a model of human heart [4, 11, 12]. Crab's electrocardiograms (EKGs) were analysed by a random-walk analysis technique that we innovated by our group [4, 5] and discovered that dying crab hearts (**Figure 3**) show a low scaling exponent [scaling index (SI)], and healthy crab hearts show a normal SI, near 1.0. Experiments on several animal species (crabs, lobsters, isopod Ligia, crayfish and insects) revealed that natural death processes decrease SI, falling towards a low level, that is, SI ≒ 0.5 [4, 5] (**Figure 4**). Then, we encountered strange specimens that exhibited a high SI, such as ~1.5. Their hearts

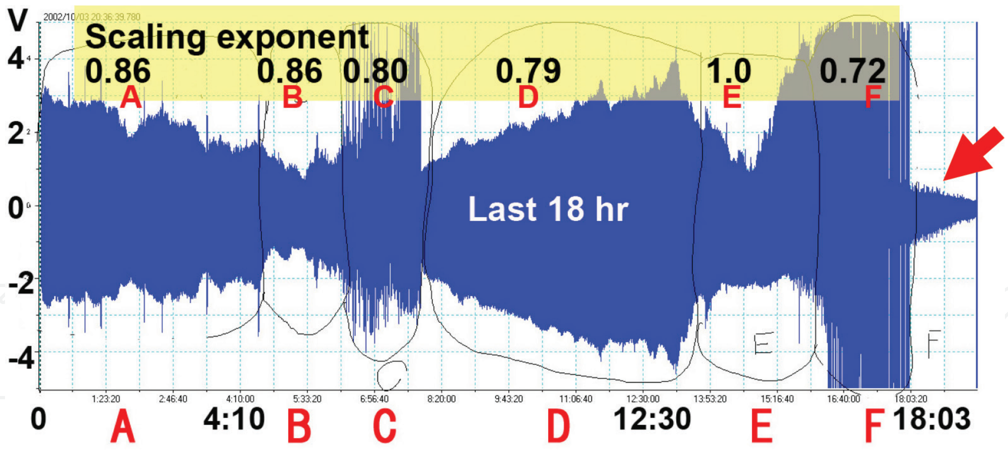


Figure 3. A natural death EKG recorded from a dying coconut crab (*Birgus latro*). From A to F, decrements in scaling exponents. Immediately after F, the heart stops pumping and fibrillation-like electrical signal remained (an arrow).

Figure 4. EKG test arena (sea water) and some specimens engaged in the tests. After mounting electrodes, EKGs were continuously recorded for the rest of their life. These specimens were terminally inconvenienced after a period of time, for example, from 2 weeks to 2 years.

stopped suddenly, meaning that they died unpredictably (**Figure 5**): we noticed that high-SI specimens are unique and of rare case. A key observation was that unpredictable death crab always had myocardial injury that was caused by the mounting of artificial EKG electrodes (**Figure 6**).

Figure 5 shows EKG data taken during the unexpected dying process. We normally put two EKG electrodes into crustacean dorsal carapace. However, this crab (**Figure 6**) received three, an excess electrode. As EKG electrodes have no good contact with the surface of heart muscles, they make EKG signal weak. We never want to damage the heart. However, this insufficient condition sometimes occurred. Any electrode can cause this unwished outcome: damaging local myocardial cells. From this unexpected outcome, we 'accidentally' obtained data that prove that myocardial damage increases SI. Then, we had an idea from this crustacean phenomenon that human ischaemic myocardium damage might be the same in terms of physiological nature, and damaged human heart might be able to be analysed with mDFA (see subsequent text).

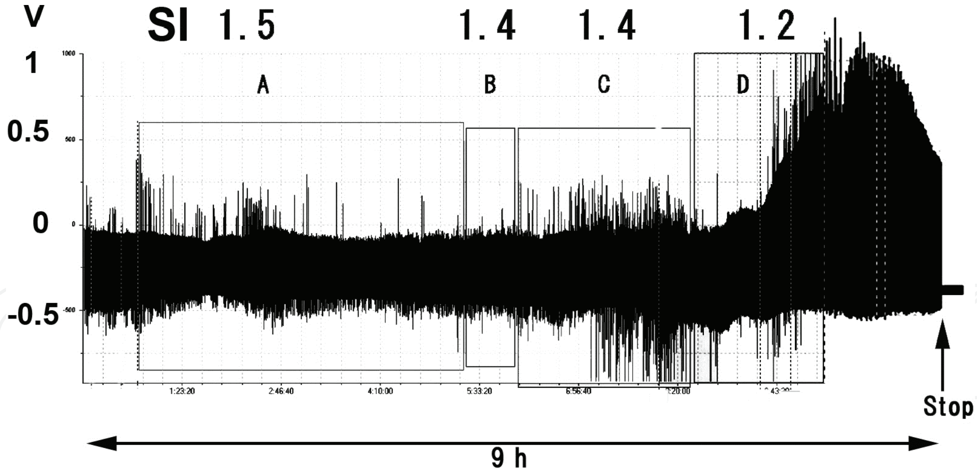


Figure 5. Unpredictable death. EKG from a crab (*Portunus* sp.). A similar experiment as shown in **Figure 3**, but this specimen's heart suddenly ceased at an arrow. Note, scaling exponents (SI) are always very high, from A to D.

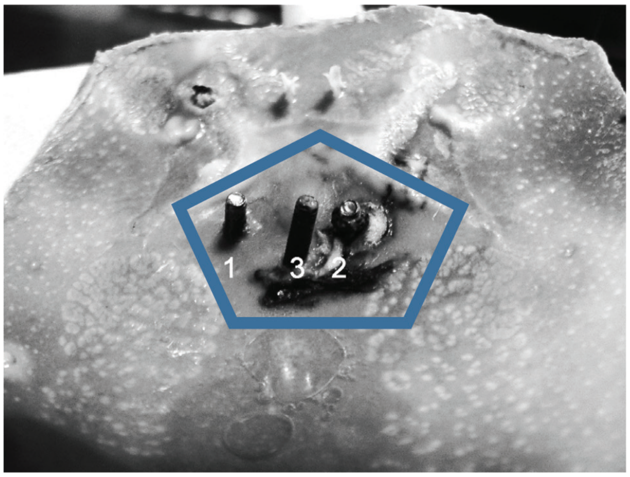


Figure 6. Inside view of a crab carapace. Gazami crab, *Portunus* sp. the approximate size of the heart is shown, pentagon-shaped diagram. This picture was taken after the crab's death. Electrode-1, -2, and -3, for EKG. Diameter of electrodes: 1 mm. One can see that electrode-3 is too long in size to damage the heart being located immediately beneath the carapace. Myocardial damage caused unpredictable cessation of heartbeat. It took 2 weeks before this crab stopped her heart pumping, which was unpredictable (see **Figure 5**).

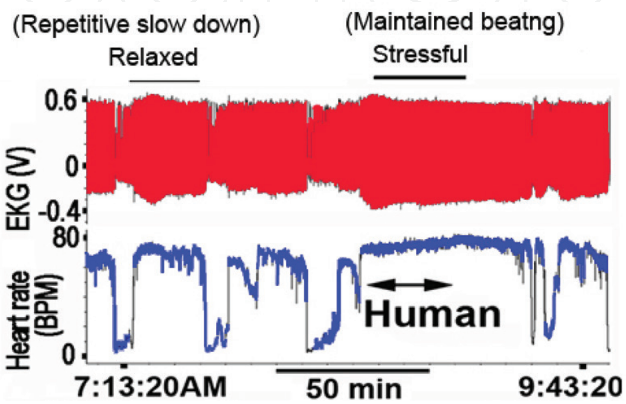


Figure 7. Intermittent-stopping manner of heartbeat. Lobster (*Panulirus japonicus*). The intermittency ceased when a human approached the lobster tank. Note: An increasing tendency of heart rate during the presence of a human (between arrows).

We believed that crustacean heartbeat continuously persists beating, that is, their hearts beat like the human heart does. But it was not the case (**Figure 7**). With EKGs from freely moving lobsters/crabs, we found that the heartbeat pattern is not continuous but intermittent if animals are not disturbed (**Figure 7**). This intermittency is induced by the activity of cardio-inhibitory nerve (**Figure 8**, [12]). Then, EKG analysis revealed that a relaxed lobster exhibits an SI near 1.0 and a nervous lobster exhibits an SI near 0.5 (**Figure 9**). These results suggested

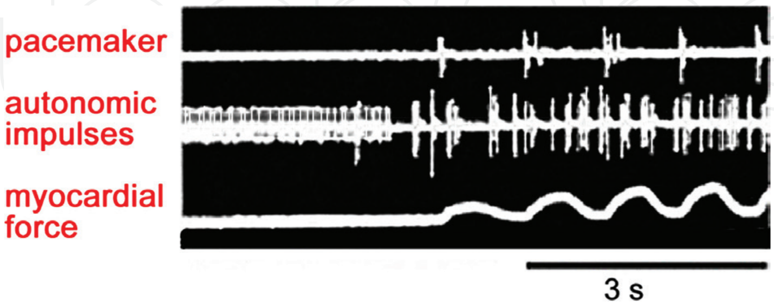
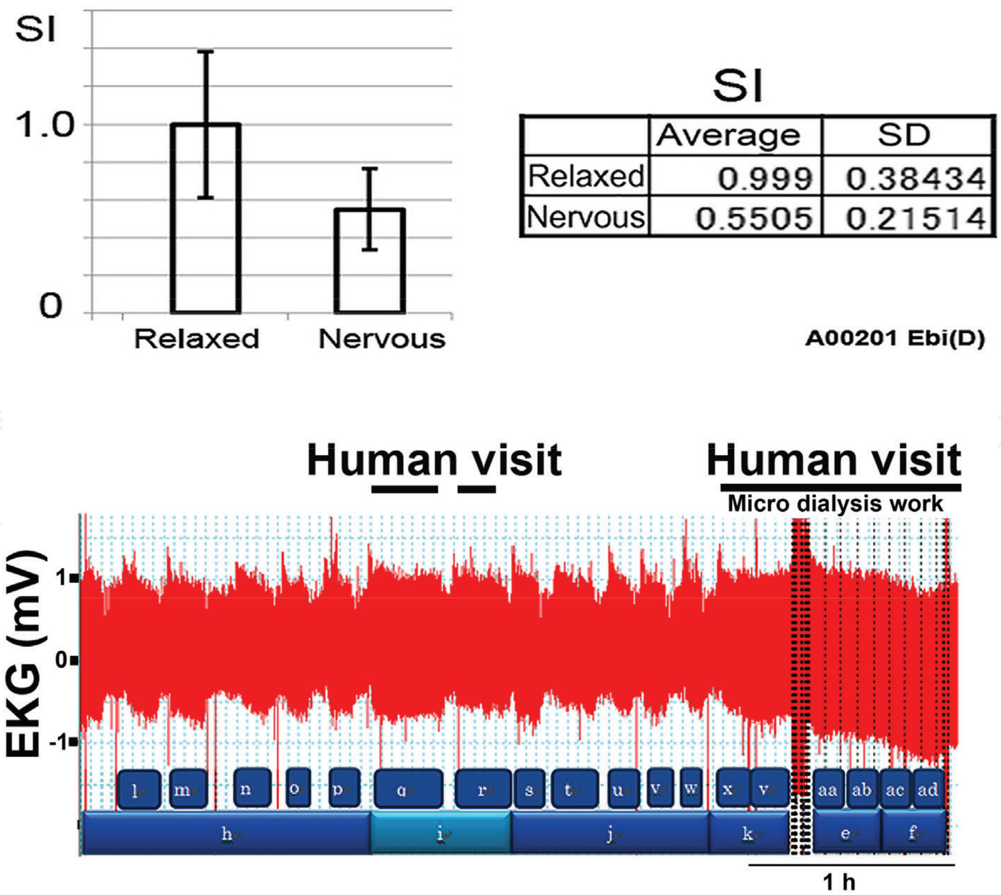


Figure 8. Simultaneous electro-physiological recording: heart (pacemaker, largest spike size, approximately 3 mV), cardio-regulatory nerve (autonomic impulses, largest spike size, approximately 500 micro-V), and mechanical transducer (myocardial force, the largest peak force of contraction is approximately 1 mg). An increase of a nerve activity corresponds to a complete stop of heartbeat. The smallest spikes in amplitude are the cardio-inhibitory impulses. The other two include the cardio-acceleratory impulses. Hermit crab (*Aniculus aniculus)* (modified from Yazawa and Kuwasawa [12]).



	Average	SD
Relaxed	0.999	0.38434
Nervous	0.5505	0.21514

Figure 9. A long EKG recording. Lobster, *Panulirus japonicus*. A human visit (thick lines) changes the heartbeat pattern. In relaxed and nervous conditions: SI ≒ 1 and SI ≒ 0.6, respectively (upper inset). SI distinguishes lobster’s psychology.

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to us that SI might be useful to quantify the psychology of lobster. Indeed, stressful stimuli decrease lobster's SI significantly, and electro-physiologically the nervous/stressful state is a state of acceleration dominant and lost-inhibition controls of the heart (**Figure 7**).

We have long been specifically studying the neurobiology of crustaceans [11]. However, the crustacean experiments opened our eyes bigger, and our viewpoint was extended to human hearts. SI measures could be applicable not only to crustaceans but also to humans at least applying to their time series signal obtained from the heartbeat. According to our guideline, the normal SI ranges approximately 0.8–0.9 < SI < 1.1–1.2 [5].

3. EKG: humans

All experimental subjects were treated as per the ethical control regulations of universities (Tokyo Metropolitan University; Tokyo Women's Medical University; Universitas Advent Indonesia, Bandung; Universitas Airlangga, Surabaya, Indonesia).

We have tested so far over 500 human individuals [5]. We have learned that SI is a useful indicator for job-related stress and/or contentment of everyday life, as well as for heart disease. Typical results from them are shown in **Table 1** (modified from Ref. [4]). When subjects reply to an interview that stress level is fairly low, the person's SI is near 1.0. In turn, subjects who have stress exhibit a low SI such as 0.7–0.8 (**Table 1**). Subjects who have ischaemic heart disease, that is, having damaged myocardium, have a high SI such as 1.2–1.4 (**Table 1**). It is worth noting that we found a correlation between a high SI and myocardial damage, when we conducted crustacean experiments (**Figures 5** and **6**).

Subject	Categories cardiac disease	Age	Stress level (interview)/daily life	SI
1	Business owner (a company)	50s, male	Fairy low	1.03
2	Business owner (a company)	50s, male	High	0.72
3	Top management, President of a Univ.	60s, male	High	0.84
4	Top management, Vice President of a Univ.	40s, female	High	0.84
5	Middle management, Dean	40s, male	High	0.72
6	Middle management, Secretary of president	40s, female	High	0.76
7	Ordinary employee, Teaching only professor	50s, male	Fairly low	1
8	Ordinary employee, Teaching only professor	50s, female	Fairly low	0.98
9	Patient with stent-placement	60, male	Daily life OK	1.26
10	Patient with bypass-surgery	45, male	Daily life OK	1.38
11	Patient with implantable cardioverter	53, male	Daily life OK	1.22
12	Ventricular septal defect (20 years ago operation)	48, female	Daily life OK	1.41
13	Healthy representative, housewife	46, female	Daily life OK	1.03

Table 1. Typical mDFA results.

4. EKG-mDFA gadget

Health wellness monitoring has been advancing in health care and medical applications [14]. We focus our attention to heartbeat checking. **Figure 10** shows lab-made data logging and mDFA computing devices for a real-time detection and measurement. **Figure 10A** shows electrodes for EKG, commercially available, in-hospital use, using for a prematurely born baby in an incubator, Vitrode V, Nihon Koden, Tokyo, Japan. **Figure 10** shows an EKG amplifier, heartbeat-interval calculator and Bluetooth radio transmitter. This EKG amplifier (**Figure 10B**) receives live-body EKG signal from the two terminals (**Figure 10A** and **B**, any two electrodes, the third one is a spare electrode). **Figure 10C** shows an iPod (Apple, USA), which has a computation program mDFA [4, 5]: We incorporated mDFA into an iPod (not for sale). This system (**Figure 10**) is commercially available except for two items: (1) mDFA program and (2) modified electrode attachment (**Figure 10B**). To us, ready-made goods (**Figure 10B**) have the inconvenience for precision recording of the heartbeat signal, because it often fails to detect R-peaks of EKG.

Figure 12 shows a practical view of iPod touch screen. To start recording, an operator can touch the button (Rec), and then after completing capture of 2000 beats, it automatically

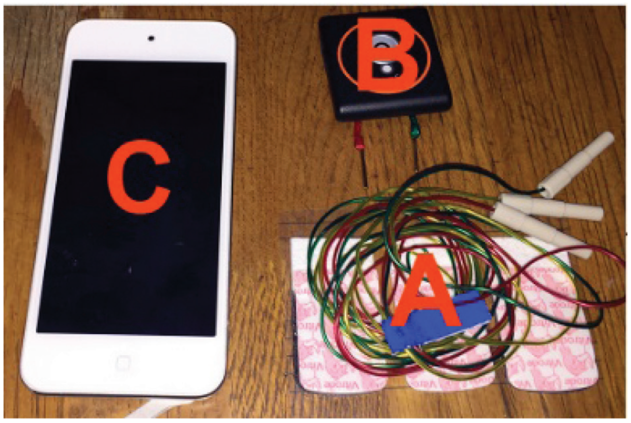

Figure 10. EKG logging and mDFA calculation, a real-time detection and measurement.

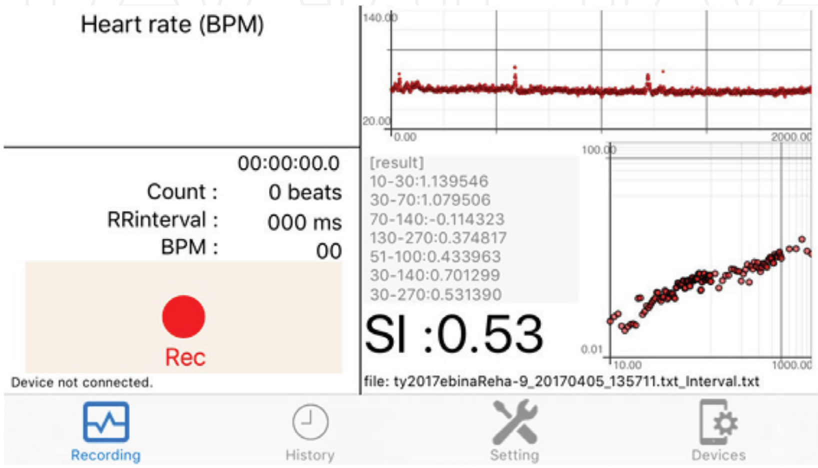

Figure 11. An example of a screen view of an iPod (lab-made, not for sale).

computes SI. As can be seen in the figure, SI is 0.53 (**Figure 11**). Generally, SIs are computed from various box size ranges: [10; 30], [30; 70], [70; 140], [130; 270], [51; 100], [30; 140] and [30; 270] (see [4, 5] in detail). For the final best SI, we take the last one, here, it is 0.531390 [30; 270], as explained in [4, 5]. Computational and mathematical explanations about mDFA are presented in [4, 5].

5. Case study 1: driving safely

Figure 12–14 show 14 results of consecutive and automated mDFA computation. A volunteer (a male aged 66) drove a car from his home to a town 150 km away to visit his mother-in-law who is hospitalised. He has been driving the road a number of times; thus he is familiar with the road conditions every corner. Furthermore, he drove safely as possible as he can by obeying the speed limit. We recorded his EKGs while driving and computed the scaling exponents (SI) using the device shown in **Figure 10**.

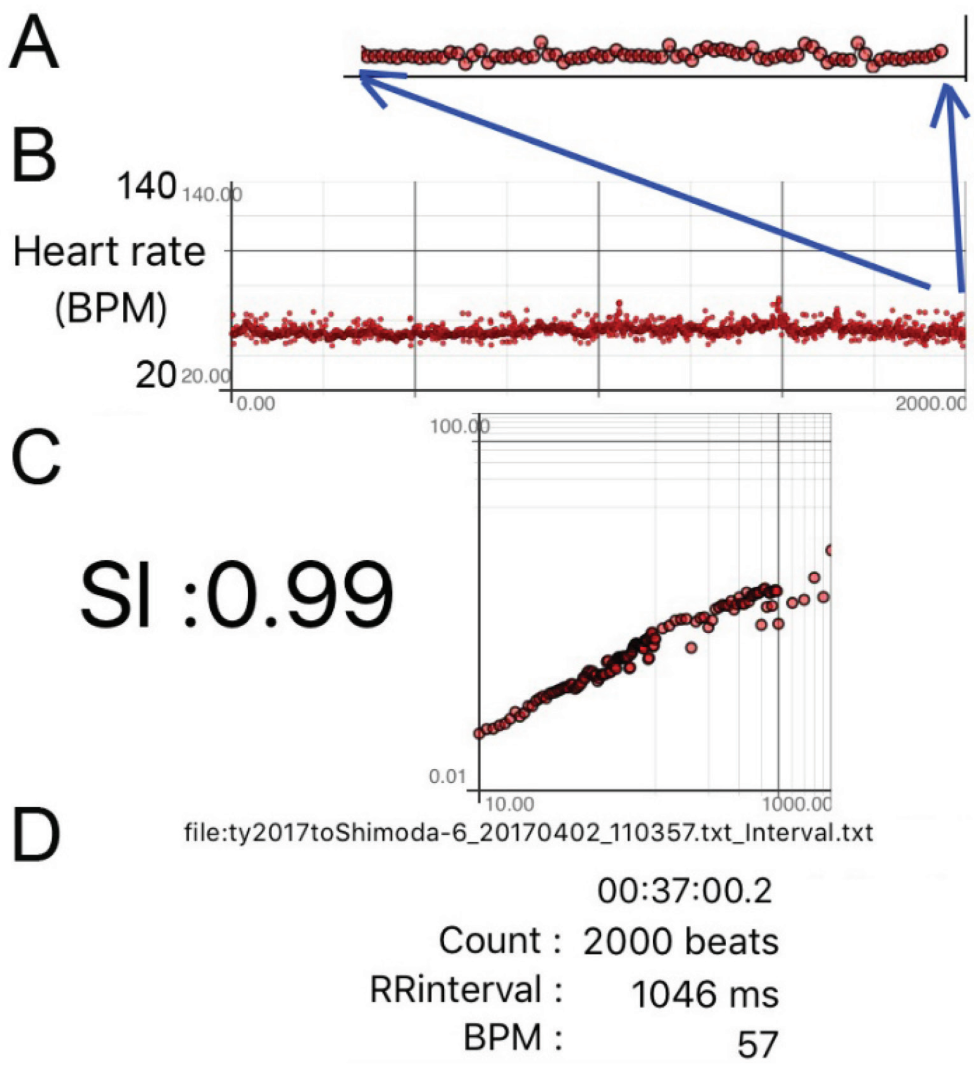

Figure 12. An example for EKG monitoring and mDFA results.

	2017Apr2, Driving a car to see relatives	SI
1	Talk about Gas, driving route, etc., before the express way	0.84
2	Express way, driving at about 70km by legal speed	1.03
3	Ordinary road, driving at about 40km by legal speed	1.09
4	Ordinary road, driving at about 40km by legal speed	1
5	Ordinary road, driving at about 40km by legal speed	1.03
6	Ordinary road, driving at about 40km by legal speed	* 0.99
7	Ordinary road, driving at about 40km by legal speed	1.04
8	Ordinary road, driving at about 40km by legal speed	1
9	Lunch, Chinease restaulant, sweet-sour pork, special black vineger	0.61
10	Visit hospital, meeting elderly mom-in-low, nervous	0.64
11	In the hospital, nervous	0.53
12	Ordinary road, driving safely, super market	0.84
13	Super market, driving safely ordinary road	0.99
14	Meeting/greeting brother-in-law, nervous conversation	0.77

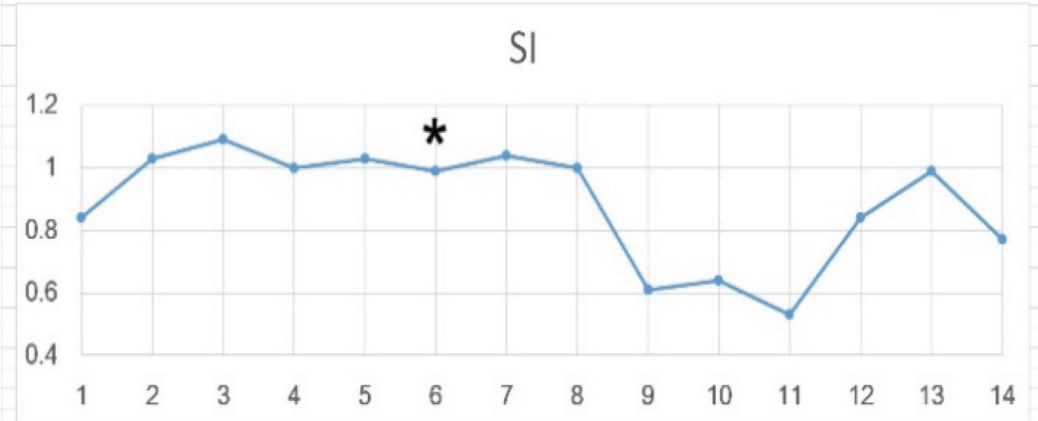

Figure 13. Fourteen consecutive EKG monitoring and resulting SIs.

The driver's heart rate was monitored by the aforementioned device (**Figure 10**). **Figure 12** shows an example result of mDFA computation. **Figure 12B** represents a 2000-beat recording, that is, an example time series. **Figure 12A** shows an expanded time series of heart rate recording (arrows). Interval signals were transferred to an iPod and stored in it. The iPod has our mDFA program [4, 5]. The program instantaneously computed the scaling exponent (SI) from the heart rate time series, immediately after capturing 2000 heartbeats (**Figure 12C**). **Figure 12D** shows a summary of the characteristics of the data (i.e. the file-name (interval. txt), 37 min and 0.2 s in total recording time for the 2000 beats, R-R interval value and heart rate (beat per min, BPM) for the last heartbeat, i.e. 1046 ms.). **Figure 12C** indicates that driving safely gives a perfect healthy scaling exponent near 1.0. Here, the SI is 0.99.

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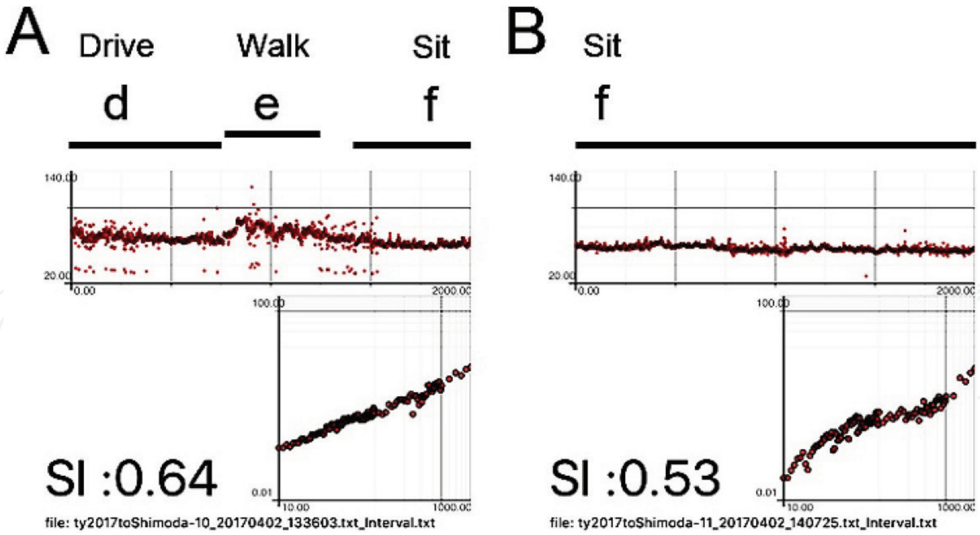

Figure 14. Two examples of iPod-mDFA. A, corresponding to **Figure 13**, number 10. B, corresponding to **Figure 13**, number 11. A 5-min break of recording between A and B. Driving the car (d), walking into the hospital (e), sitting in the room of the patient (f).

Figure 13 summarises results of driving-mDFA test. At first, SI showed a low value (SI = 0.84, **Figure 13**, number 1). This can be explained that the driver handled many worries about fuel gas, driving route and so force. After taking the express way, the driver maintained a speed limit (70 km/h) and enjoyed the blue sky of a spring morning day (SI = 1.03, **Figure 13**, number 2). Many vehicles overtook his car one right after the other although some law-abiding cars followed his car. He continued driving safely (**Figure 13**). One can see that his safe driving gave good values of SI, that is, near 1.0 as can be seen in the SI values from 2 to 8 (**Figure 13**).

It is very unique result that a specific behaviour, eating lunch, decreased the SI value (SI = 0.61, **Figure 13**, number 9). We can explain these results as the following: the mind (his brain function, i.e. autonomic nerve function) concentrated to enjoying foods, digesting them in the stomach and even pay less attention to environment. It seems that a dynamic CVCS response to environment is not dominant when eating lunch.

One can see that SI decreased when the subject walked into the hospital and visited/stayed in the room of his mother-in-law (see **Figure 13**, numbers 10 and 11, SI = 0.64 and 0.53, respectively). After going out from the hospital, SI recovered: during driving and shopping at the super market (see **Figure 13**, numbers 12 and 13). We would like to conclude that mDFA can capture anxiety/worry of a subject.

The last result (**Figure 13**, number 14, SI = 0.77) is interesting. When meeting a new person (the driver's brother-in-law) in order to greet him, SI decreased again to a very low value (**Figure 13**, number 14, SI = 0.77), which indicates that the volunteer subject is very nervous. He said that he tried NOT to display an ungentlemanly attitude to the son of mother-in-law.

Figure 14 shows two examples of iPod-mDFA screen view. This might give convincing evidence for the idea that 'stressfulness decreases SI'. We would like to emphasise that iPod-mDFA is beneficial more than we have expected.

In conclusion, stress decreases SI down to a lower value. We would like to emphasise that three examples, SI = 0.64, and SI = 0.53, SI = 0.77, are great results of iPod-mDFA gadget, and read-out time after 2000 heartbeat detections is only 1–2 s. All SI monitoring were instantaneously computed by iPod-mDFA system as shown in **Figure 13**.

6. Case study 2: overseas flight

A volunteer (a male aged 66) travelled by air from the Narita-Tokyo Airport to the Washington Dulles International Airport in order to attend a conference held in the USA. Using the iPod device, we recorded his EKGs and computed the scaling exponents as shown in **Figure 15**. Twenty-four SI measurements during the flight were documented and plotted, from which we found that mDFA accomplished understandable results similar to that shown in **Figure 13**.

We confirmed that the SI values can represent the internal world of the subject (see **Figure 15**). For example, when the subject was at an aroused state such as in the waiting lounge (see 1 in **Figure 15**), watching an exciting documentary (note: highly personalised expression), and preparing for landing (see 24 in **Figure 15**), the SI is near 1.0. In turn, when watching a movie which has an emotional involvement (note: highly personalised expression), the heartbeat of subject shows a lower SI values (see 18–20 in **Figure 15**). Finally, when the subject is at asleep condition, the SI decreases significantly (see 7–9 in **Figure 15**).

In conclusion, a happy life could fundamentally guarantee a healthy exponent. Anxiety and stress lowered the scaling exponent. mDFA might reflect psychological and physical internal bodily state. mDFA might look at the internal state through the heart. The heart is the window of the mind.

7. Uncertainty and accuracy of mDFA computation

7.1. Physics/mathematics

Readers of this article might have questions about the uncertainty and accuracy when it comes to the acquisition of the data points.

We must identify all R-peaks (R-peak within a single heartbeat of EKG trace) to construct a heartbeat-interval time series. Firstly, we put a red-mark sign on top of each and every R-peak. Unfortunately, our computer does miss some R-peaks due to the movement of subjects (animals). There are two major reasons for that. One is inevitable drift of baseline of EKG trace. The other is electric-originated or muscle-movement-originated spike-like noises. Therefore, secondly in our study, we always check/repair each and every R-peak by eyes on a PC screen. This is NOT easy tasks but must-do tasks for us; we decided so in the beginning of

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	2017 3/20 NRT-WDC	SI
1	Waiting lounge, embarkation	1.06
2	Taxi, take-off, a disturbing kid next seat	0.74
3	Climbing flight, a disturbing kid next seat	0.86
4	Red wine service	0.91
5	Meal service, talked to the neibour thus feeling less stress	0.93
6	Meal, coffee, feeling sleepy	0.91
7	Fall asleep	0.67
8	Fall asleep	0.57
9	Fall asleep	0.54
10	Feeling sleepy	0.76
11	A long yawn, drowsy but watch a video, Mr. W. Disney	0.83
12	W. Disney history	0.89
13	W. Disney history, watch a documentary, Stars	0.86
14	Feel half awake	0.78
15	Stars, then a documentary, Petra	1.05
16	Petra, talk to a flight attendant, drinks	0.84
17	A yawn, a movie Asia, then a movie, Mr. Church, Eddy Murphy	0.9
18	Mr. Church, emotional involvement	0.76
19	Mr. Church, emotional involvement	0.77
20	Mr. Church, emotional involvement	0.77
21	Mr. Church, next movie, not so interesting	0.79
22	Movie, sleepy	0.73
23	Fall asleep	0.6
24	Sleepy but announcement "approacing WD airport"	0.95
	low battery condition	

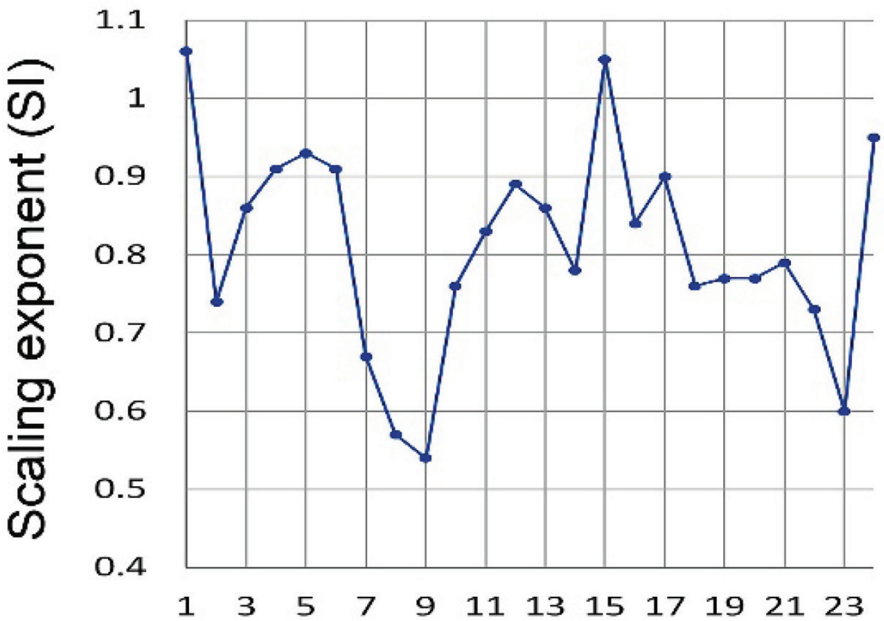

Figure 15. mDFA results during **a** 13-h overseas flight.

this study. As a result, our time series obtained from any subjects are a 100% accurate. It is a perfectly captured R-R interval data: prematured ventricular contractions, atrial fibrillations, whatever it is.

mDFA computes SI values. For a given time series data, mDFA returns only one SI. If you repeat this procedure for a given time series, you get an exactly the same SI value. Readers can imagine an artificial time series that is, for example, a white noise-like fluctuation data, it gives a scaling exponent of 0.5. A random-walk-like time series data give a scaling exponent of 1.5. However, 1/f time series (SI = 1.0) is very difficult to make artificially, definitely because 1/f-spectrum-like fluctuation is an outcome from natural dynamic phenomena. In short, a structure of a time series gives a single SI. It is mathematically accurate.

7.2. Biology/medicine

The uncertainty derives from the uncertainty of BioMedicine. The problem to be solved is how we interpret the meaning of SI. We agree that it could be a controversial issue for the people who read this article without doing experiments. Diagnosis/interpretation of data is never perfect, but SI calculation is accurate and perfect.

I recall my childhood: cicadas sing during the day of sunny summer days. It is like under perfect condition they sing. At night, I hear insects most of them were a cricket or a katydid. Whenever ‘a boy of a curious nature’ tried to capture them, he experienced, the insects stop singing if he approached too closer to them. Typically, animals do not love human approaching.

A few people have asked me if lobsters/crabs feel stress. My answer is ‘yes’ although there is a problem regarding the uncertainty and accuracy (see earlier text). The truth is not known yet, because animals never tell us how they feel. But they indeed sense a human. At least, the truth that we found is SI changes when they sense a human (**Figures 7** and **9**).

We can explain that SI measure is like temperature measure (Celsius, C degree). SI has a criterion value as temperature does. If C is 37°, our healthiness is fine as far as temperature is of concern. In the same way, if SI is one (1.0), healthiness is fine. 1/f is comparable to SI = 1. It has been shown by Kobayashi and Musha in 1982 [1] and Peng et al. in 1990s [2, 3]. In those days, when Kobayashi et al. worked, their computer never had enough power to quickly calculate/handle the time series data.

In short, the scaling exponent (SI) is accurate. The uncertainty derives from our interpretation. For our guide line, believe it or not, you may have no problem for the heart if you have SI, ranging $0.8 < SI < 1.2$.

8. Conclusion

This study suggests that the scaling exponents (SI) computed by mDFA can quantify stress. Furthermore, mDFA results were intriguing: cardiac muscle injury can be detected using mDFA. An ischaemic heart has a high SI. Before these findings, we already have proven in animal models that injured crustacean hearts exhibited a high exponent [4, 5].

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Although we need much more comprehensive examples, we propose that mDFA is a helpful and beneficial computation tool in the research on emotion, particularly fear and anxiety disorders, understanding how emotion is encoded in the heartbeat time series, in animal models and humans.

If the body is tortured by stimuli from environment, and/or if some stimuli would harm us internally, which is invisible from outside, we would be upsetting for the nervous system. If we use mDFA, we can realise that stimuli is distorting the autonomic nerve function, little of which has been understood by a human being until today [13], although we spend everyday under advanced science and technology. We would like to emphasise that, using mDFA computation, we can numerically evaluate/quantify the state of our body, even if it is invisible to us.

Although we (basic scientists, biologists) cannot make by ourselves, making a gadget is very rewarding. It is the right time to start making it. The gadget can work: (1) recording 2000 consecutive heartbeats without missing even a single pulse, (2) computing automatically the scaling exponent that can check the scaling exponent = 1.0, which is perfectly healthy state [4, 5], and finally (3) the gadget would capture what is going on in front of, around, and inside our mind. It gives us health information, for example, each time we use it on an everyday basis.

In the present paper, we would suggest that we have entered the world experiencing seeing inside without sight. Sometimes, a new technology does not have to be supercomplicated. mDFA computation is a kind of high school-level mathematics instead of sophisticated nonlinear measures and/or linear complex computation like the HRV, the heart rate variability. mDFA looks at how the brain communicates with the heart and also with the world. mDFA is a tool that enables us to explore previously uncharted territories. For both preventive and post-diagnostic health wellness monitoring [14], we hope that the market might find this beneficial nature of mDFA.

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Author details

Toru Yazawa

Address all correspondence to: yazawa-tohru@tmu.ac.jp

Biological Science, Tokyo Metropolitan University, Hachioji, Tokyo, Japan

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