Characteristic Extraction of Mental Disease Patients by Nonlinear Analysis of Plethysmograms

Yuyu Hu[a], Wenbiao Wang[b], Takashi Suzuki[c] and Mayumi Oyama-Higa[d]

[a,,b,c,,d] *Graduate School of Osaka University*

Abstract. We measured the pulse waves of 196 mentally ill patients and 113 healthy students. Using heartbeat changes, we calculated the values of their sympathetic nerves, parasympathetic nerves, and autonomic nerve balance. In addition, we calculated the largest Lyapunov exponents (LLE) by non-linear analysis of plethysmograms. Values were analyzed by group. The results revealed a significant relationship between LLE and the autonomic nerve balance. The sympathetic nerve values in the patient group were significantly higher than those in the student group, whereas the LLE values were significantly lower. Furthermore, we illustrated the dynamic change in the results for single participants over several testing times. The measurement of pulse waves is easy and economical and does not put a strain on the subject. Additionally, these values can provide information that is more accurate than medical examination obtained from an interview. Our study contributed to the existing methodology in this field, and future data collection and measurement will be carried out. We hope that our study will be useful for neurologists and psychotherapists in their detection and treatment of mental illness.

Keywords: plethysmogram, mental illness, the largest Lyapunov exponent, autonomic nerve balance.
PACS: 05.45, 02.50, 02.70

INTRODUCTION

In Japan, it is said [http://journal.mycom.co.jp/news/2008/04/14/017/index.html] that 1 of every 15 people experiences depression at some point in his or her lifetime. Depression is closely associated with suicide [http://ja.wikipedia.org/wiki/%E3%81%86%E3%81%A4%E7%97%85]

The total number of people suffering from depression in Japan which was 433,000 in 1996 and 1,041,000 in 2008, has increased by 2.4 times over the 9 years[from 2000 to 2008] according to "the patient investigation" held every three years by Japanese Ministry of Health, Labor and Welfare [http://www.mhlw.go.jp/toukei/list/10-20.html], and depression has become a serious social problem.

These statistics only represent the total number of patients diagnosed with "mood disorders" (depression, manic-depressive psychosis, dysthymia). Additionally, the data are provided by medical institutions, and do not include individuals who are not being treated by a doctor.

Depression is a mental disorder marked by sudden feelings of melancholia, anxiety, and feelings of worthlessness. One main cause is extremely high stress in the workplace.[http://utu-genin.sublimeblog.net/]

Early detection of depression is necessary for sustained mental health in everyday life. In this study, we examined how physiological data of depression sufferers differed from those of individuals in good health.

EXPERIMENT

Participants

A professional counselor who has a private practice in Tokyo measured the pulse waves of the mentally ill patients. The mental disease patient receives an ill diagnosis name to show in table 1 from a psychiatrist. Age of the patients is just what to show it in table 1, but the sex is unclear.

The student data were collected from healthy university students Kwansei Gakuin University, Nishinomiya, Japan） Male: 42. Female: 71, Age average:19.61, standard deviation: 1.90. Informed consent was obtained from all participants in the study. Figure 1 shows the distribution of the participants in the study. Table 1 presents the number of times the pulse waves were measured, the patients' ages, the patients' diagnoses, and the total duration of the pulse waves measurement in a sub-sample of the patient group.

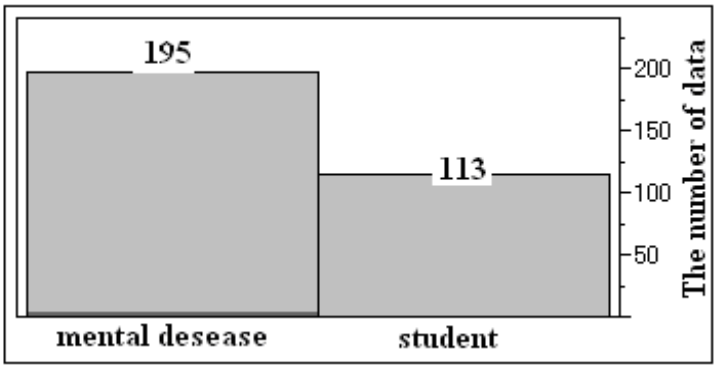


FIGURE 1. Distribution of the participants in the study

Procedure

After obtaining informed consent, we measured the pulse waves using a photoplethysmography sensor (CCI BC2000). The room temperature was 25°C.

Each subject was asked to sit in a chair and keep his or her eyes open during the measurements, which were taken using a cuff attached to the left index finger. For each measurement, the pulse waves of the mentally healthy students were measured for three minutes, whereas those of the mentally ill patients were measured more than three minutes Because the measurement of pulse waves more than two minutes is necessary to calculate autonomic nerve balance.

TABLE 1 Partial list of the mentally ill patients included in the calculations

File No.	times	Age	Name of Mental disease
300001	2	45	Major Depressive Disorder / Primary Sleep Disorder
300003	3	46	Cyclothymic Disorder
300004	4	31	Eating Disorders / Organic Psychotic Disorder (due to the Hypothyroidism)
300006	1	40	Major Depressive Disorder(Simple)
300020	2	19	Brief Pcychotic Disorder(due to remarkable stressing factor)
300021	3	29	Organic Psychotic Disorder (due to the hypothyroidism)
300023	1	45	Bipolar II Disorder
300027	11	41	Cyclothymic Disorder / Obsessive Compulsive Disorder
300036	2	45	Adjustment Disorder
300040	1	38	PMS / Organic Psychotic Disorder
300048	4	37	Schizophrenia(Paranoid)
300062	3	31	Schizophrenia Disorder / Dysthymic Disorder
300075	2	41	Schizophrenia Disorder / Dysthymic Disorder
300078	3	36	Obsessive-Compulsive Disorder
300092	4	40	Agoraphobia
300109	2	37	Dysthymic Disorder
300121	5	15	Asperger's Symptoms
300133	2	38	Schizoaffective Disorder (Depressive Disorder type)
300136	5	46	Generalized Anxiety Disorders
300140	1	29	Eating Disorders･ Premenstrual Catatonic Disorder
300147	3	36	Cyclothymic Disorder
300152	2	29	Generalized Anxiety Disorders
300161	3	33	Schizoaffective Disorder (Depressive Disorder type)
300165	1	33	Eating Disorders
300173	6	32	Social Phobia
300189	2	42	Dysthymic Disorder･ PTSD･ multiple chemical sensitivity
300206	3	26	Schizoaffective Disorder (Depressive Disorder type)
300232	2	41	Organic Psychotic Disorder (Hashimoto's)
300239	7	30	Dysthymic Disorder / Obsessive-Compulsive Disorder

RESULTS

Analysis of plethysmograms using Lyspect software

We analyzed the plethysmograms using Lyspect software (Chaos Technology Research Lab, Shiga, Japan). Lyspect is able to perform three types of analyses, namely, chaos analysis, blood vessel-balance analysis, and autonomic nerve-balance analysis using finger plethysmograms as input data.

Figures 2 and 3 show the results for two mentally ill patients. Unusual results can be seen.

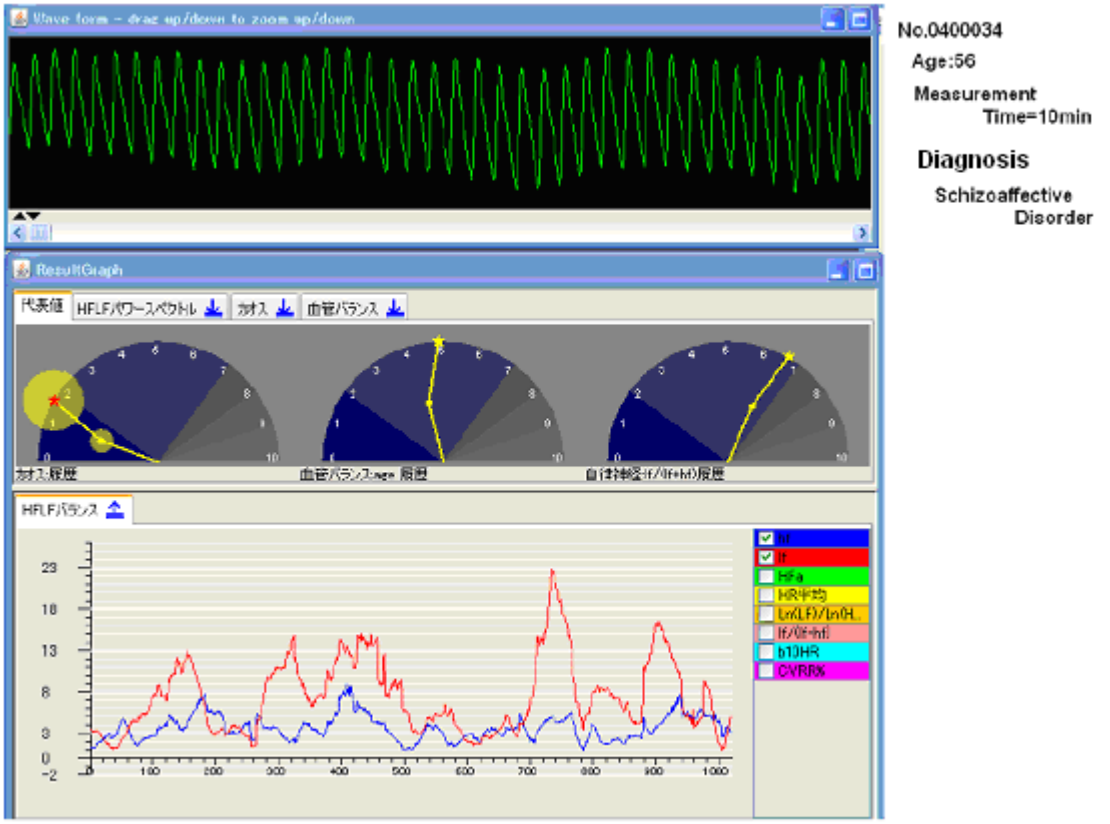


FIGURE 2. Results for patient A (Schizoaffective Disorder)

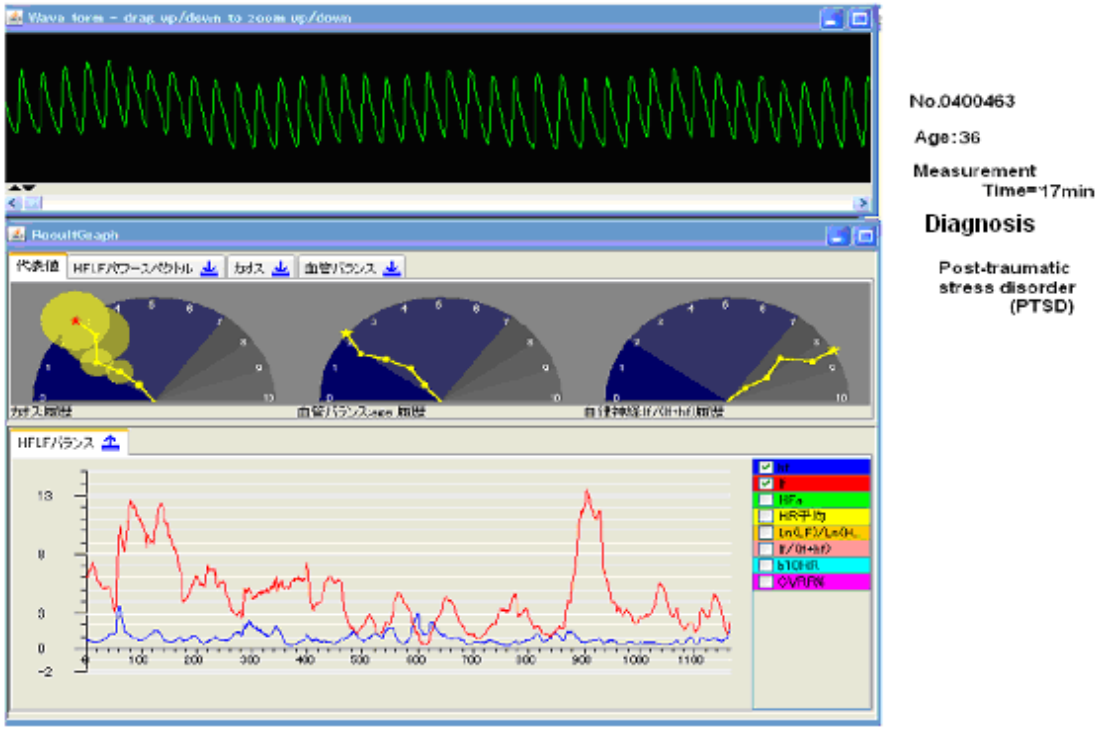


FIGURE 3. Results for patient B (Post-traumatic Stress Disorder)

The top panel shows the pulse wave. In the middle panel, three semicircles display, from the left, LLE, blood vessel balance, and autonomic nerve balance, respectively. Each semicircular graph represents a scale of 0–10, and a normalized value for each time is shown by the angle of the line drawn in yellow. The line graph in the bottom panel shows changes in values for the sympathetic (LF, in red) and parasympathetic nerves (HF, in blue) with respect to time.

The patients in Figures 2 and 3 were diagnosed with schizoaffective disorder and post-traumatic stress disorder, respectively. In both graphs, LLE is low, and the autonomic nerve balance is >5. In other words, it can be understood that the sympathetic nerves were dominant over the parasympathetic nerves.

The values shown in Figures 2 and 3 are averages obtained through several measurements. That is, results of several measurement times are shown in the figures.

Across multiple measurements in each patient, LLE and the autonomic nerve balance display a stable value. We are confident that the results of the repeated measurements are reliable.

Identification of characteristic patterns in mentally ill patients

Of the seven variables calculated using Lyspect, we sought one or more variables that represented the characteristic data of these mentally ill patients.

The values of LLE and autonomic nerve balance appear to reflect data characteristic of the mentally ill patients. Figure 4 shows the relationship between LLE and autonomic nerve balance in the patient and student groups.

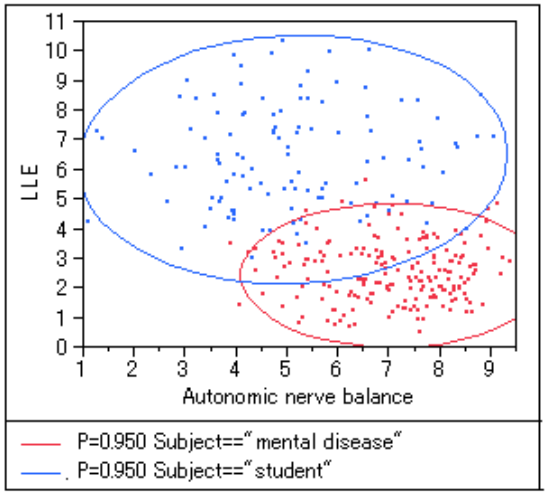


FIGURE 4. The relationship between LLE and autonomic-nerve balance
[Figure 4 shows all data on (LLE = Y axis , Autonomic nurve balance = X axis) space.
Mental disease group (red) and Student group(blue) is shown with an establishment oval of 95%.]

With respect to LF and HF, the power spectrum analyzes change in the frequency of the heartbeat period.

- High-frequency domain (HF): 0.15 Hz–0.40 Hz (parasympathetic)

• Low-frequency domain (LF): 0.04 Hz–0.15 Hz (sympathetic nerve + parasympathetic)

To calculate the area of the domain mentioned above, we obtained LF and HF.

hf = HF/(HF + LF)

b10= (1-hf) *10

Here, b10 is autonomic-nerve balance where $0 \leqq b10 \leqq 10$. Then, $b10 < 5$ indicates parasympathetic predominance, and $b10 > 5$ indicates sympathetic predominance

Autonomic nerve balance analysis

Figure 5 shows the results of a one-way ANOVA on the autonomic nerve balance.

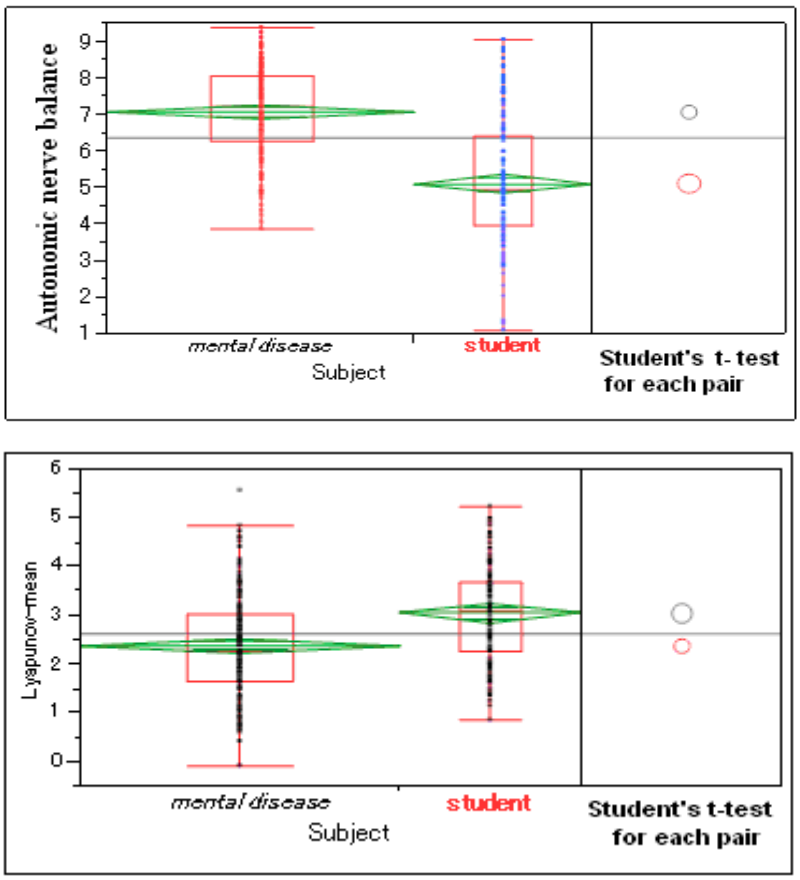


FIGURE 5. Comparison of the average autonomic-nerve balance and LLE between a mentally ill patient and a healthy individual

Detection of mental illness using pulse waves

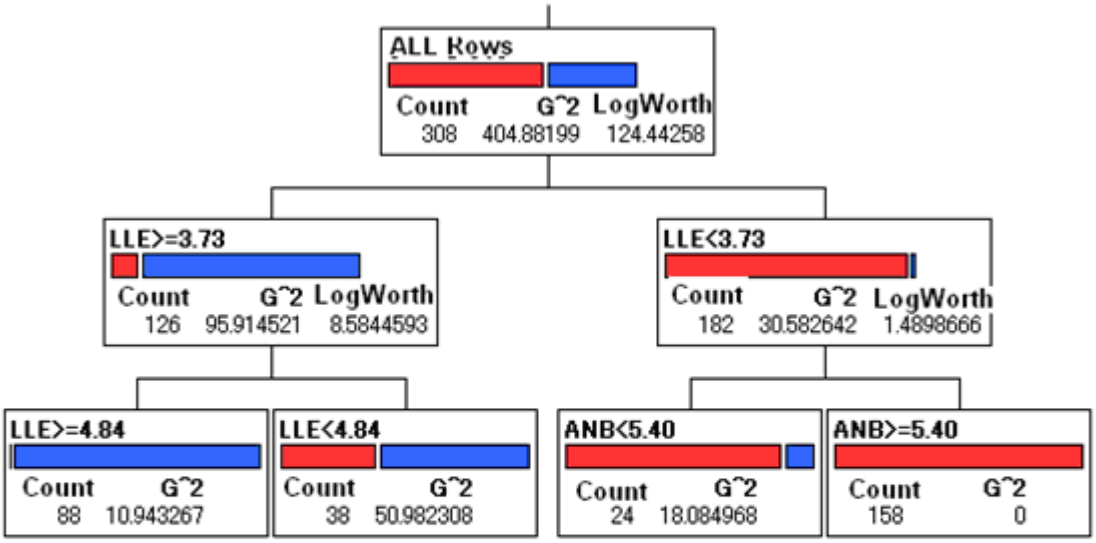
Figure 6 shows the rules for distinguishing mentally ill patients from mentally healthy individuals using partition analysis.

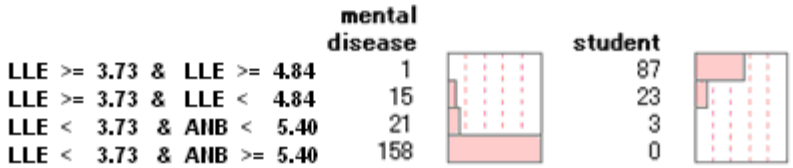
Here, ANB is autonomic nerve balance.

The total sample size is 308, including 195 mentally ill patients and 113 mentally healthy individuals.

For partition analysis,

Rule 1 LLE ≥4.84: Mentally health (Student) = 87
Rule 2 3.73 ≤ LLE < 4.84: Mentally healthy = 23, Mentally ill = 15
Rule 3 LLE <3.73 & ANB < 5.40 Mentally ill = 21, Mentally healthy = 3
Rule 4 LLE <3.73 & ANB ≥5.40 Mentally ill (Patients) = 158





FUGURE 6 The distinction rule for the mentally ill patients and mentally healthy individuals using partition analysis

Discriminant analysis

In the following, we denote LLE and ANB by variables VAR00001 and VAR00002, respectively.

TABLE 2. Discriminant weights of the variables

	Function 1
VAR00001	.911
VAR00002	-.436

TABLE 3. Discriminant loadings of the variables

	Function 1
VAR00001	.900
VAR00002	-.414

Tables 2 and 3 show the discriminant weights and discriminant loadings respectively, which reflect the contribution of the two variables to the function.

TABLE4 Unstandardized coefficients

	Function
	1
VAR00001	.696
VAR00002	-.306
(Constant)	-.734

Table 4 shows the unstandardized coefficients, which enabled us to directly calculate the unstandardized function:

$$f = - 0.734 + VAR00001 * 0.696 - VAR00002 * 0.306.$$

TABLE 5. Unstandardized canonical discriminant functions

	Function
VAR00003	1
.00	-1.221
1.00	2.108

Table 5 shows the unstandardized canonical discriminant functions evaluated at the group means, where VAR00003 is a two-valued notation, which equals .00 or 1.00, representing a mentally ill participant or a healthy participant, respectively; the right side shows their magnitudes. Thus, using the number of mentally ill and healthy participants, the critical value can be obtained:

$$y = (- 1.221 * 195 + 2.108 * 113) / 308 = 0.171213.$$

We judged whether a participant suffered from mental illness by comparing the values of f and y: the participant was classified as mentally ill if $f < y$ and as mentally healthy if $f > y$.

TABLE 6. Classification results

			Predicted Group Membership		
		VAR00003	.00	1.00	Total
Original	Count	.00	190	5	195
		1.00	10	103	113
	%	.00	97.4	2.6	100.0
		1.00	8.8	91.2	100.0
Cross-validated(a)	Count	.00	189	6	195
		1.00	10	103	113
	%	.00	96.9	3.1	100.0
		1.00	8.8	91.2	100.0

Table 6 presents the classification results for the participants. We were able to correctly classify 97.4% of the mentally ill patients and 91.2% of the mentally healthy students in our sample.

DISCUSSION AND CONCLUSION

This study has identified characteristic physiological patterns of mentally ill patients

with various indexes using pulse waves measurement with the aim of fostering optimal care for mentally ill patients. We utilized a simple measurement methodology to detect mental illness to help mentally ill people receive effective treatments as early as possible.

We collected data through several measurements from the same patient, ensuring reliability of the analysis. Furthermore, we compared the characteristic physiological patterns of mentally ill patients with the data of mentally healthy students.

From the results of the analysis, we obtained a significant difference between these groups in LLE and autonomic nerve balance.

Notably, we developed a system that could display the activity of sympathetic nerves, parasympathetic nerves, and LLE at the same time, while simultaneously measuring the pulse wave.

This system allows us to assess the mental status of a patient while measuring the patient's pulse wave.

We hope to obtain additional measurement data of more mentally ill patients in the future. We also intend to conduct a study in which we will identify mental illness by analyzing the pulse wave result.

The system we developed can be used as a means of early detection of mental illness and can assess patients' mental state.

We hope that this system can help provide better medical care for mental illness.

ACKNOWLEDGMENTS

We deeply thank Dr. Oshima, president and psychological counselor at the Insight Counseling Corporation (Tokyo, Japan), who provided the pulse waves measurements of the mentally ill patients and diagnoses of their mental illnesses.
We thank Dr. Shomura who provided the English names of the mental illnesses.

REFERENCES

1. Oyama-Higa M., Miao T., and Mizuno-Matsumoto Y. (2006). Analysis of dementia in aged subjects through chaos analysis of fingertip pulse waves. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2863–2867.
2. Tsuda I., Tahara T., and Iwanaga I. (1992). Chaotic pulsation in capillary vessels and its dependence on mental and physical conditions. Int. J. of Bifurcation and Chaos 2: 313–324.
3. Takens F. (1985). In: Braaksma B. L. J., Broer H. W., and Takens F., eds. Dynamical Systems and Bifurcations, Lecture Notes in Math. Vol. 1125. Springer, Heidelberg. Sano M., and Sawada Y., 1985. Measurement of the Lyapunov spectrum from a chaotic time series. Phys. Rev. Lett. 55: 1082.
4. Miao T., Shimoyama O., & Oyama-Higa M. (2006). Modeling plethysmogram dynamics based on baroreflex under higher cerebral influences. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2868–2873.
5. Oyama-Higa M., & Miao T. (2006). Discovery and application of a new index for cognitive psychology. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2040–2044.

6. Imanishi A., & Oyama-Higa M. (2006). The relation between observers' psychophysiological conditions and human errors during monitoring task. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2035–2039.
7. Imanishi A., & Oyama-Higa M. (2006). The relation between observers' psychophysiological conditions and human errors during monitoring task. 2006 IEEE Conference on Systems, Man, and Cybernetics, Taipei, Taiwan, 2035–2039.