Identifying Characteristic Physiological Patterns of Mentally Ill Patients using Nonlinear Analysis of Plethysmograms

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Abstract: We measured the pulse waves of 195 mentally ill patients and 113 healthy students. Using heartbeat changes, we calculated the values which represent the intensity of their sympathetic and parasympathetic activities, and the values of their autonomic nerve balance (ANB). In addition, we obtained 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 ANB. 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 are likely to 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 illnesses.

1 INTRODUCTION

The total number of people suffering from depression in Japan which was 433,000 in 1996 and 1,041,000 in 2008, has increased to 2.4 times over the 13 years according to "the patient investigation" held every three years by Japanese Ministry of Health, Labour and Welfare. Depression, a mental disorder marked by sudden feelings of melancholia, anxiety, and worthlessness, which is closely related to suicide, has become a serious social problem.

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

This study has succeeded in identifying the characteristic patterns of mentally disease sufferers in terms of certain physiological indexes. Furthermore, a self-check system has been developed, enabling people to check their status of mental health in a convenient and economical way.

The next section will describe the experiment and explain the method, namely, chaos analysis, which is essential in this study and has been effectively applied in numerous previous studies. Then the following section will give the analysis and results in details.

2 EXPERIMENT AND METHOD

2.1 Subjects

A professional counsellor helped measure the pulse waves of the mentally ill patients, whose ages and names of diseases are shown in Table 1. The gender is undisclosed.

The students' data were collected from healthy university students of Kwansei Gakuin University in Nishinomiya, Japan. They include 42 males and 71 females, with the average age of 19.61 and the standard deviation of 1.90. Informed consent was obtained from all participants in the study. Table 1 also presents the number of times the pulse waves were measured, and the total duration of the pulse waves measurement in a sub-sample of the patient group.

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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

2.2 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 time of the measurement, the pulse waves of each subject were measured for at least three minutes, since the measurement for more than two minutes is necessary to correctly calculate the autonomic nerve balance (ANB), which is an important parameter in our study and will be explained in Section 3.1.

2.3 Method of Chaos Analysis—The Calculation of Largest Lyapunov Exponent

It has been evidenced that time series data with deterministic chaos can be constituted by fingertip plethysmograms (Tsuda, Tahara and Iwanaga, 1992).

Let

$$x(i),\ i = 1, 2, ...$$

denote the time series data. By the method of delays, the phase space is reconstructed, which contains vectors in the form of

$$X(i) = (x(i), x(i-\tau), ..., x(i-(d-1)\tau)) = \{x_k(i)\}_{i=1}^{d}, \quad (1)$$

where τ is a constant delay, d is the embedding dimension and

$$x_k(i) = x(i-(k-1)\tau),\ i = 1, ..., d. \quad (2)$$

In order to reconstruct the phase space correctly, the parameters of the delay τ and the dimension d should be chosen optimally (Abarbanel et al., 1993). In our study, considering the time series recorded from fingertip pulse waves, it has been shown that the optimal choice is $\tau = 50\ ms$ and $d = 4$ (Sano and Sawada, 1985; Sumida et al., 2000).

The largest Lyapunov exponent (LLE) is one of the essential measures of complexity in the reconstructed phase space, which reflects the divergence of the attractor trajectory. Considering *X(t)* as the evolution with time from some initial trajectory *X(0)*, LLE is given by

$$LLE = \lim_{t\to\infty} \lim_{\epsilon\to 0} \frac{1}{t} \log \frac{|\delta X_\epsilon(t)|}{|\epsilon|}, \quad (3)$$

where

$$\delta X_\epsilon(t) = X(t) - X_\epsilon(t) \quad (4)$$

and the initial difference vector

$$\epsilon = X(0) - X_\epsilon(0) \quad (5)$$

in the phase space. LLE is estimated by applying the algorithm of Sano and Sawada (1985).

Figure 1 shows the plethysmogram and attractor obtained from the measurements, and LLE obtained.

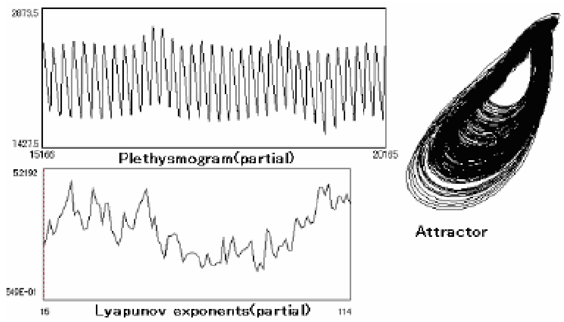

Figure 1: Plethysmogram (top), attractor (right) and LLE (bottom).

Previous studies (Imanishi and Oyama-Higa, 2006; Oyama-Higa and Miao, 2006; Oyama-Higa, Miao and Mizuno-Matsumoto, 2006) have shown that LLE serves as a significant indicator of mental immunity. The values of LLE of a mentally healthy individual fluctuate within a reasonable scope. When LLE is abnormally high, the mental immunity of the individual is so strong that he or she is likely to go to extremes, such as committing crime. On the other hand, when it is abnormally low, the mental immunity is so weak that the individual is prone to mental illnesses.

3 ANALYSIS AND RESULT

3.1 Analysis of Plethysmograms using "Lyspect"

We analyzed the plethysmograms using a software called Lyspect, developed by Chaos Technology Research Lab in Shiga, Japan. Lyspect is able to perform chaos analysis and analysis of ANB, using finger plethysmograms as input data.

The top panel shows the pulse wave. In the middle panel, three semicircles display, from the left, LLE, blood vessel balance, and ANB, respectively. Each semicircular graph represents a normalized scale of 0–10, and a 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 low frequency of heartbeat period (LF, in red) and high frequency (HF, in blue) with respect to time.

To put it concretely, HF is referred to in the scale of 0.15-0.40 Hz, which reflects the parasympathetic activity; LF is in the domain of 0.04-0.15 Hz, which is influenced by both sympathetic and parasympathetic nerves. ANB is defined as normalized value:

$$ANB = 10\left(1 - \frac{HF}{HF + LF}\right) \in [0, 10]. \quad (6)$$

$ANB < 5$ indicates parasympathetic predominance, and $ANB > 5$ indicates sympathetic predominance.

The patients in Figures 2 and 3 are diagnosed with schizoaffective disorder and post-traumatic stress disorder, respectively. In both graphs, LLE is low, and ANB is greater than 5.

Notice that 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. Through several times of measurements for each patient, LLE and ANB tend to be stable, so we are confident that the results of the repeated measurements are reliable.

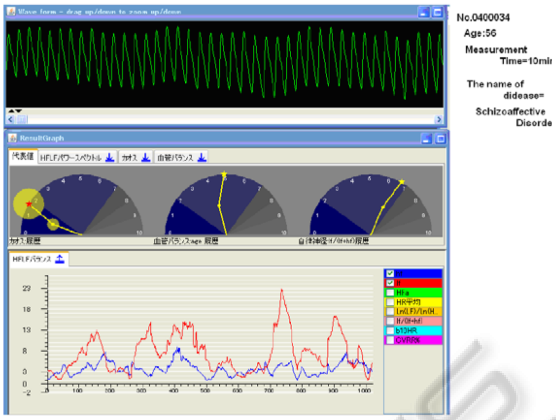

Figure 2: Results for patient A (Schizoaffective Disorder).

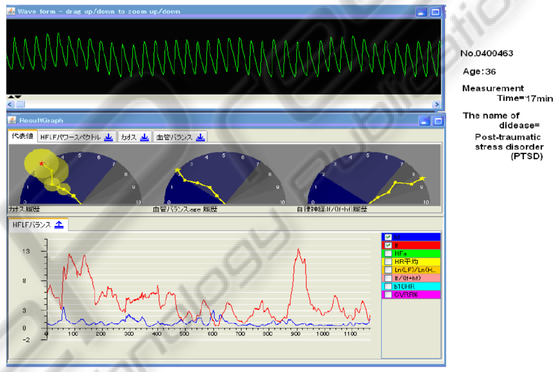

Figure 3: Results for patient B (Post-traumatic Stress Disorder).

3.2 Identification of Characteristic Patterns in Mentally Ill Patients

The values of LLE and ANB are found to reflect data characteristic of the mentally ill patients. Figure 4 shows the relationship between LLE and ANB in the patient and student groups.

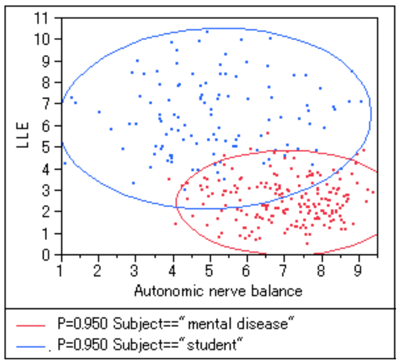

Figure 4: The relationship between LLE and ANB [All the data are shown. Mental ill patients' group (red) and healthy students' group (blue) are shown with an establishment oval of 95%].

3.3 Autonomic Nerve Balance Analysis

Figure 5 shows the results of a one-way ANOVA on the ANB.

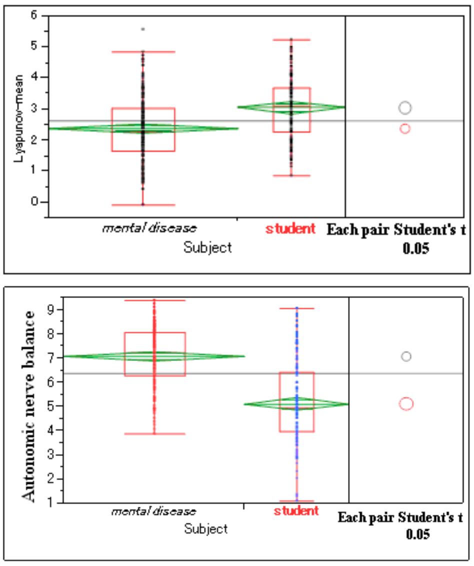

Figure 5: Comparison of the average ANB and LLE between a mentally ill patient and a healthy individual.

3.4 Detection of Mental Illnesses using Pulse Waves

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

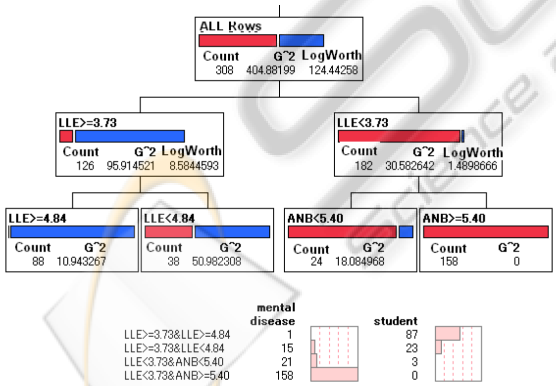

Figure 6: The distinction rule for the mentally ill patients and mentally healthy individuals using partition analysis.

Recall that the total sample size is 308, including 195 mentally ill patients and 113 mentally healthy students. For partition analysis,

Rule 1. $LLE \geq 4.84$: the number of mentally healthy students is 87;

Rule 2. $3.73 \leq LLE < 4.84$: the numbers of mentally healthy students and mentally ill patients are 23 and 15 respectively;

Rule 3. $LLE < 3.73$ and $ANB < 5.40$: the numbers of students and patients are 3 and 21 respectively;

Rule 4. $LLE < 3.73$ and $ANB \geq 5.40$: the number of patients is 158.

3.5 Discriminant Analysis

In this subsection, discriminant analysis is carried out with the help of statistical software.

Table 2: Discriminant weights of the variables.

	Function
LLE	0.911
ANB	-0.436

Table 3: Discriminant loadings of the variables.

	Function
LLE	0.900
ANB	-0.414

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

Table 4: Unstandardized coefficients.

	Function
LLE	0.696
ANB	-0.306
Constant	-0.734

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

$$f = -0.734 + LLE \times 0.696 - ANB \times 0.306. \tag{7}$$

Table 5: Unstandardized canonical discriminant functions.

V	Function
0	-1.221
1	2.108

Table 5 shows the unstandardized canonical discriminant functions evaluated at the group means, where V is a two-valued notation, which equals 0 or 1, 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:

$$y = \frac{-1.221 \times 195 + 2.108 \times 113}{308} = 0.171213. \quad (8)$$

We judged whether a participant suffered from mental illnesses 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.

		V	Predicted group membership		Total
			0	1	
Original	Count	0	190	5	195
		1	10	103	113
	Percentage	0	97.4	2.6	100.0
		1	8.8	91.2	100.0
Cross-validated	Count	0	189	6	195
		1	10	103	113
	Percentage	0	96.9	3.1	100.0
		1	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.

4 CONCLUSIONS AND REMARK

To conclude, this study has identified characteristic physiological patterns of mentally ill patients using pulse waves measurement. From the results of the analysis, we obtained a significant difference between these groups in LLE and ANB.

Notably, this system can display the activity of sympathetic nerves, parasympathetic nerves, and LLE at the same time, which enables us to assess the mental status of patients when measuring their fingertip pulse waves. Furthermore, the methodology is simple and the operation is economical. It can be used for early detection of mental illnesses.

We hope that this system can contribute to promoting better medical care. We will strive to collect and analyze more data of mentally illness sufferers, and intend to continue relevant studies in the future.

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REFERENCES

Abarbanel, H. D. I., Brown, R., Sidorowich, J. J., Tsimring, L. S. (1993). The Analysis of Observed Chaotic Data in Physical Systems. Rev. Mod. Phys., 65, 1331-1992.

Imanishi, A. and Oyama-Higa, M. (2006). The Relation Between Observers' Psychophysiological Conditions and Human Errors During Monitoring Task. 2006 IEEE Conference on Systems, Man, and Cybernetics, 2035–2039.

Ministry and Health, Labour and Welfare (Japan). (n.d.). The patient investigation. Retrieved March 26, 2012, from http://www.mhlw.go.jp/toukei/list/10-20.html

Oyama-Higa, M. and Miao, T. (2006). Discovery and Application of New Index for Cognitive Psychology. 2006 IEEE Conference on Systems, Man, and Cybernetics, 2040–2044.

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, 2863–2867.

Sano, M. and Sawada, Y. (1985). Measurement of the Lyapunov Spectrum From a Chaotic Time Series. Phys. Rev. Lett., 55, 1082-1085.

Sumida, T., Arimitu, Y., Tahara, T. and Iwanaga, H. (2000). Mental Conditions Reflected by the Chaos of Pulsation in Capillary Vessels. Int. J. Bifurcation and Chaos, 10, 2245–2255.

Tsuda, I., Tahara, T. and Iwanaga, I. (1992). Chaotic Pulsation in Capillary Vessels and Its Dependence on Mental and Physical Conditions. Int. J. Bifurcation and Chaos, 2, 313–324.