POSSIBILITY OF MENTAL HEALTH SELF-CHECKS USING DIVERGENCE PROPERTIES OF PULSE WAVES

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Abstract: We conducted a nonlinear analysis of fingertip pulse waves and found that the Lyapunov exponent having the "divergence" property of attractor trajectory was an effective index for estimating human mental health. We showed that this method is effective for an early detection of dementia and depression, as well as in the detection of changes in mental status. In addition, based on these results obtained from time series analysis of the recorded pulse waves, we developed an application device allowing easily installed and convenient measurement for daily check and monitoring mental/physical status. It was an easy-to-use and cost-less device installed in a PC mouse. Also, we studied a representation method of constellation graphs to disclose the fluctuation details of the Lyapunov exponents. In the representation, changes in mental status were assessed and graphically visible by using of the fluctuation factor of the Lyapunov exponents.

1 INTRODUCTION

Some serious mental health problems exist in Japan. For example, the number of annual suicides has reached 30,000 for three consecutive years 2004 to 2006.Most suicides are related to depressive symptoms. In addition, although Japan has the world's highest longevity rate, the cases of dementia increase along with the rapidly increase in the aged population, thereby leading to some social problems (ref. plala, http). Social and family responses are essential to help those with depression and dementia, but in most cases, these diseases progress without self-acknowledged, and hence need the necessary methods for an early detection and treatment.

It is generally necessary to check the status of behavior and mental health in daily life to detect the onset of depression and dementia. Subjective observation alone is insufficient; it is required to evaluate objective data using scientific methods. So far, scientific methods include the analysis of brain waves and image diagnosis of the brain, which require high levels of technology and knowledge; these are not simple measurement methods in terms of time or cost. Therefore, easy and economical measurement methods are required.

The Lyapunov exponent referencing the "divergence" of an attractor trajectory in the nonlinear analysis of fingertip pulse waves is an effective method for assessing mental health in humans (Tsuda 1992). In particular, it was found to be effective for the detection of dementia and the diagnosis of depression (Oyama-Higa 2006). In section 2, we describe the method used to calculate the "divergence value" using the nonlinear analysis of fingertip waves. In section 3, we explain the meaning of the use of fingertip pulse waves and the relation between the "divergence value" and cognitive psychology. In section 4, the relation between the Lyapunov exponent and mental health is explained. In section 5, we show the representation method of constellation graphs developed for mental health self-checks. Finally, we outline our future work, and make some discussions in relating to possible applications.

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2 METHODS OF RECORDING AND ANALYSIS OF FINGERTIP PULSE WAVES

2.1 Recording Method of Fingertip Pulse Wave

Fingertip pulse waves were measured by photo-plethysmography method. Changes in the amount of hemoglobin flowing through the capillaries were measured by infrared photo-electric method (Fig. 1). The waveform is naturally synchronized with the beating of the heart. Dynamics changes in hemoglobin levels caused by the constriction of capillaries in the fingertip constitute time series data from a complex system that includes information from the sympathetic and parasympathetic nerve. Changes in hemoglobin levels in the capillaries are thought to be related to the baroreceptor, which are linked to the sympathetic and parasympathetic nerve via the brain stem and spinal cord (Figure. 2). Pulse wave data were collected at a sampling frequency of 200 Hz with a resolution of 12 bits. The measurement duration was variable, depending on the experimental conditions. Time series data consisting of 12,000 points can be obtained in 1 min of measurement.

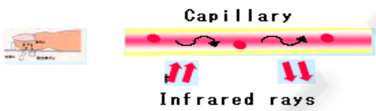

Figure 1: Measurement of pulse waves using infrared irradiation of capillaries.

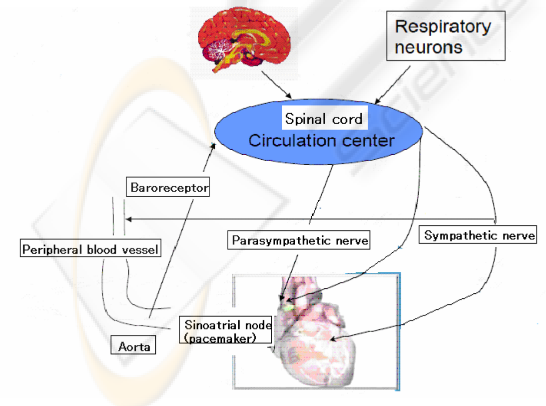

Figure 2: Diagrammatic representation of the interaction from brain stem to peripheral blood vessels through the action of sympathetic and parasympathetic nerves.

This is a convenient measurement method because it does not require special care with regard to room temperature, place of measurement, and measurement conditions. Moreover, because the measurement time is very short, the collection of data is not a burden to the subject.

2.2 Chaos Analysis of the Pulse Wave

Fingertip pulse waves were demonstrated to have chaotic characteristics (Tsuda1992, Sumida 2000, and Miao 2006). On the basis of chaotic analysis of time series, we analyzed the recorded data to determine divergence properties of the pulse waves. In chaos analysis, the attractor was reconstructing using time delay method (Tarkens,1981,1985). The parameters used are delay time of 50 ms and embedding dimension 4.

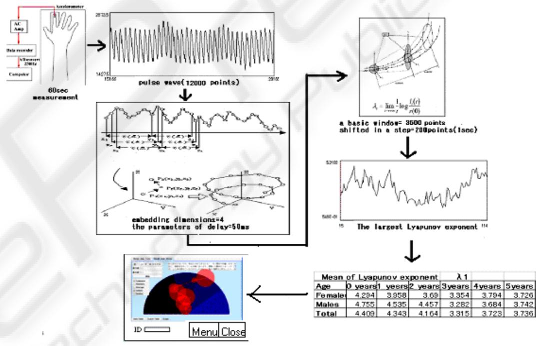

Figure 3: Procedure from measurement of pulse waves to Lyapunov exponent computations.

Beside of the effective information obtainable from the shape of the four-dimensional attractor, we calculated the Lyapunov exponent, which is an index of trajectory instability and a characteristic of chaos, using Sano and Sawada algorithm (Sano and Sawada 1985).
As shown in Figure 4, we used the following method to calculate the Lyapunov exponent. We assumed that a small sphere (hypersphere) of radius ε is the initial value for a three-dimensional chaotic dynamic system. After being mapped once, the sphere was stretched in the e1 direction and compressed in the e3 direction, and assumed the shape of an ellipsoid (Figure. 4). We designated the logarithm of the expansion rate per unit time along the directions e1, e2, and e3 as $\lambda 1$, $\lambda 2$, and $\lambda 3$, respectively. Here, $\lambda 1$, $\lambda 2$, and $\lambda 3$ are the Lyapunov exponents and their set is the Lyapunov spectrum. Because four embedded dimensions were set as the optimum number of dimensions for the pulse wave, w obtained the four Lyapunov exponents, $\lambda 1$, $\lambda 2$, $\lambda 3$ and $\lambda 4$, as the

Lyapunov spectrum. Of these, the largest Lyapunov exponent, λ1, was used in the calculation to prepare the constellation graphs.

The following equations show the method of calculating the Lyapunov exponent. For the time series data x(i), with i = 1, 2,…, N obtained from the fingertip pulse waves, the phase space was reconstructed using the method of time delays. Assuming that we create a d-dimensional phase space using a constant time delay τ, the vectors in the space are generated as d-tuples from the time series and are given by

$$\mathbf{X}(i) = (x(i), \ldots, x(i-(d-1)\tau)) = \{x_k(i)\} \tag{1}$$

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

To reconstruct the phase space correctly, the parameters of delay (τ) and embedding dimensions (d) should be chosen optimally (Sano and Sawada, 1985). In time series data recorded from human finger photoplethysmograms, we chose the parameters τ = 50 ms and d = 4, as in (Tsuda, 1992) and (Sumida, 2000).

In the reconstructed phase space, one of the important measures of complexity is the largest Lyapunov exponent λ1. If $\mathbf{X}(t)$ is the evolution of some initial orbit $\mathbf{X}(0)$ in the phase space with time, then

$$\lambda_1 = \lim_{t\to\infty}\lim_{\varepsilon\to 0}\frac{1}{t}\ln\frac{|\delta\mathbf{X}_\varepsilon(t)|}{|\varepsilon|} \tag{2}$$

where

$$\delta\mathbf{X}_\varepsilon(t) = \mathbf{X}(t) - \mathbf{X}_\varepsilon(t) \text{ and } \varepsilon = \mathbf{X}(0) - \mathbf{X}_\varepsilon(0)$$

for almost all initial difference vectors $\varepsilon = \mathbf{X}(0) - \mathbf{X}_\varepsilon(0)$. We estimated λ_1 using the algorithm of Sano and Sawada (1985), where λ_1 describes the divergence and instability of the orbits in phase space.

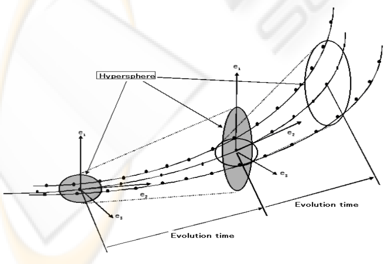

Figure 4: Method used to calculate the Lyapunov exponent.

The initial 8000 points of pulse wave data were taken as one window to calculate the largest Lyapunov exponent, λ1. In the next step, the window was shifted by 200 points and the exponent was calculated from the next window of 8000 points. This procedure was repeated until the pulse wave data were exhausted. Three minutes of measurement yielded 36,000 data points; therefore, we can obtain a (36,000 – 8000)/200 = 140-point time series of Lyapunov exponents. With 1 min of measurement, we can achieve a (12,000 – 8000)/200 = 20-point time series of Lyapunov exponents. The variation in the largest Lyapunov exponent is a measure of the variation in the trajectory of the four-dimensional attractor. The largest Lyapunov exponent is the divergence of the attractor trajectory and is an important value related to psychological indices (Oyama-Higa, 2005, 2006).

3 ESTIMATING PHYSIOLOGICAL AND PSYCHOLOGY STATUS

3.1 Outline of Self-checking Method

The subjects were asked to answer some simple questions to ensure the normal measurement of pulse waves. This information was used to interpret the observed divergence in measured values. The questions were status-checking items regarding physical conditions and a simple assessment of their mood at the time of measurement. Answers were chosen from one of three available levels (Table 1). In addition to these questions, the subjects were asked to describe their mood and condition at the time of the measurement in more definite terms (Table 1). This enabled the person to identify factors that can affect divergence values. Because these records were made in free-form style, key words alone could be used. However, when a subject is allowed to write freely, for example, about things that he or she had communicated to a friend, music he or she enjoyed, positive results in a sporting activity, and good or bad news that had been received, it is easier to study the relationships between these events and the divergence value.

The types of situations that elicit emotions such as delight, anger, sorrow, and pleasure differ from person to person. For example, a condition that creates a suitable level of divergence, such as listening to music or having a conversation with someone, must be recorded as data unique to that subject. In addition, extreme tension, fatigue, and low spirits also cause changes in divergence. Therefore, comparing the status recorded at the time of measurement with the corresponding divergence values helps a person to assess his or her own mental status. The responses and simple comments on the subject's condition are stored so that they can be seen by clicking the corresponding divergence value on the graph. We plan to vary the simple questions asked according to the category of the subject, e.g., child, adult, or aged person.

Table 1: Checking items of subjective evaluation of subject's state.

Status	Good	Normal	Poor
Sleep	v		
Appetite		v	
Health	v		
Will to work		v	
Mental health			v
Current mood			v

Freestyle reporting: The subject enters a note on his or her condition at the time of measurement. These notes can be in the form of a descriptive comment on the subject's condition, keywords, and other comments.
Comment example 1: [Had a pleasant chat with a friend about hobbies.]
Comment example 2: [Feeling low after failing a test.]

3.2 Divergence Analysis for Various Physiological and Psychological Status

Biological systems are considered to be complex and fluctuating, with chaotic characteristics. Although chaotic systems appear to be extremely complicated and to behave in a random and unstable manner, they in fact change according to deterministic rules. Biological signals emanating from humans or vital signs come in many types, such as body temperature, blood pressure, and pulse rate. Fingertip pulse waves are biological signals that produce time series data with chaotic characteristics. Moreover, unlike cardiac waves, fingertip pulse waves contain various types of information, including information from the nervous system. In the field of psychology, several methods have been suggested as indices for assessing mental health. However, these methods are generally subjective and therefore intrinsically lacking in objectivity. Questionnaires have often been used as relatively simple psychological tests, and the measurement and analysis of brain waves can be used to objectively assess the neurological state at the time of measurement. However, the measurements are not simple and the analysis methods are not yet suitable for analyzing detailed psychological changes. Another possible method for measuring biological information is to analyze the R–R intervals of heartbeats and pulse waves. However, no analysis has attempted to take into account the chaotic characteristics of biological information.

The Lyapunov exponent is a property of chaotic systems that expresses the attractor and represents the "divergence" of the attractor trajectory. We focused on the Lyapunov exponent, which has not previously been evaluated quantitatively as an index of psychological change in humans, and investigated its relationships to dementia and communication skills (an ADL index) in aged persons (Oyama-Higa,2006), its relationship to error rate at work (Imanishi,2006), its relationship to diurnal changes and indices of cumulative fatigue in employees (Miao,2006),(Oyama-Higa,2006), and time series fluctuations in divergence in 0- to 5-year-old children, as well as the effects of parental affection toward children (Oyama-Higa,2006).

It became clear that suitable functioning and harmony of the sympathetic nerves, which are related to adaptability to the external environment and to society, as well as to flexibility, spontaneity, and cooperativeness of the mind, are important for humans to live in a mentally healthy state. These values were related to the largest Lyapunov exponent obtained using nonlinear analysis (Oyama-Higa, 2005, 2006). The largest Lyapunov exponent, which represents the time series variation in the attractor trajectory, is defined as the "divergence." When this value remains low continuously (i.e., when a long period with low divergence persists), the person has low ability to adapt to the external world in daily life and is incapable of maintaining a mentally healthy state. However, a continuously high level of divergence indicates an extremely tense or stressful state. A mentally healthy state also cannot be maintained in this situation. Normally in humans, a healthy state is indicated by the condition in which constant variation occurs in the divergence.

Emotions are a part of being human, and these are believed to cause the variation in divergence.

Physical immunity is critical for the maintenance of human health, and lowered immunity causes various diseases. Therefore, to prevent the lowering of physical immunity and to increase resistance and prevent diseases, we pay attention to what we eat and we rest, take medicine when necessary, and exercise to improve our stamina. However, mental toughness, as reflected in the ability to communicate in a positive manner, willingness to perform a given job, and the ability of mental toughness to withstand dramatic changes in the external world, are also very important. We can call these “mental immunity,” but no methods have been developed to scientifically investigate this kind of immunity. We analyzed fingertip pulse waves using nonlinear analysis, examined their relationships to various psychological indices, and found that the largest Lyapunov exponent obtained through chaos analysis, which corresponds to the “divergence” of the attractor, was closely related to mental immunity. This value was also closely linked with the functioning of the sympathetic nerves of the autonomic nervous system.

For humans, a mentally healthy condition means having the ability to cope flexibly with external changes in “divergence.” This can be considered mental flexibility or mental immunity, in contrast to physical immunity. Mental immunity represents adaptability to the external changes that a person has to face in his or her everyday life, including a person’s ability to communicate and express oneself, and the suitability of psychological flexibility. When expressing themselves, humans skilfully fend off various types of changes, contacts, and assaults from the external environment, and deal with or cope with them. This is the essence of mental immunity. Change occurs constantly in day-to-day life. “Divergence,” which represents a change in the state of mental immunity, is a critical index. At the same time, divergence varies depending on the condition of the person. For example, a long period without “divergence” suggests that the person is not in a normal state. In examples of the attractors of a mentally healthy person and patients with depressive psychosis, the depressed patients have low divergence (Figure. 5). In patients with dementia, the divergence becomes smaller as dementia advances (Figure. 6).

In a normal state, the level of divergence fluctuates constantly. During times of extreme tension and stress, the divergence will be continuously high. Afterward, however, a mentally healthy person naturally finds a way to relax, which brings the divergence back to its normal state. A low level of divergence would continue when a person is in a depressed state or when age-related dementia is present. This suggests that the person is incapable of bringing the divergence back to its natural level on his or her own, indicating decreased adaptability to the external environment.

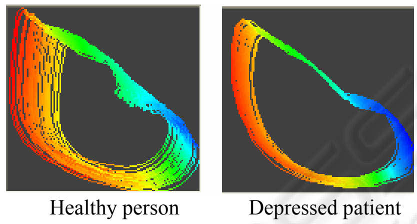

Figure 5: Attractors of a healthy person and a depressed patient prepared from 30 s of measurements.

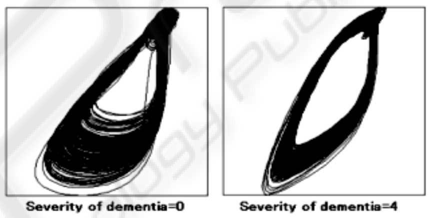

Figure 6: Attractors in elderly subjects with dementia of (severity = 0) and (severity = 4) severity.

4 CASE STUDIES AND A SYSTEM FOR MENTAL HEALTH

All measurements were taken after obtaining the informed consent of subjects.

4.1 Studies of Aged Subjects with Different Communication Skills

Subjects: Data were obtained from 179 subjects (40 males; 139 females) at three nursing homes for the aged in Shiga prefecture, Japan.

Date of measurement: August to November 2003. Measurement method: Fingertip pulse waves were measured three times for 3 min each. Systolic blood pressure, diastolic blood pressure, pulse, and body temperature were measured with the patient in a relaxed state at 25ºC (room temperature) prior to the measurement of pulse waves.

Indices: Five grades indicating the severity of dementia judged by a doctor. We obtained data for the ADL index of communication skills (threegraded evaluation), composed of seven items and estimated by a care manager. We examined the relation between the data and the maximum Lyapunov exponent calculated from the fingertip pulse waves.

Results: There was a significant relation between the maximum Lyapunov exponent and communication skills (Figure 7 A) and severity of dementia (Figure 7 B). t-student test was used.

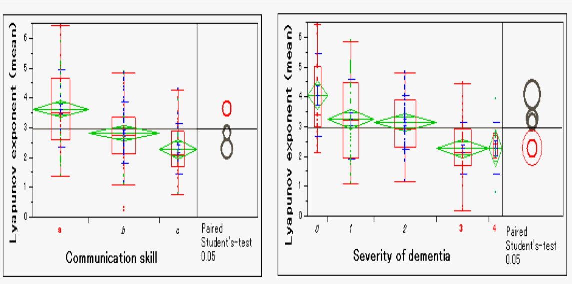

Figure 7: Relation of the Lyapunov exponent and (A) communication skills and (B) severity of dementia in elderly patients.

In constellation graphs, the right side indicates small Lyapunov exponents and the left side indicates large Lyapunov exponents (Figures. 7, 8). Because of the large quantity of data, five cases that were similar to the median of data for each rank in index (i.e., dementia, 0–4; communication skills, a–c) are shown.

Fifteen subjects with high cognition were selected and measurements were retaken after 9 months, in August 2004 (Figure. 10). Values of the Lyapunov exponent increased in some subjects and decreased in others compared to the first measurements taken in November 2003. These results indicate that changes in the Lyapunov exponent always occur. However, attention is needed to understand the causes of very low values.

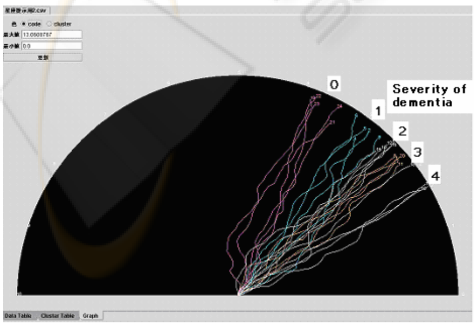

Figure 8: Relation between severity of dementia (0–4) and the Lyapunov exponent. One line indicates one subject.

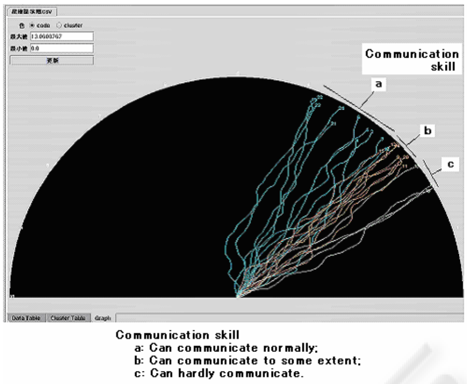

Figure 9: Relation between communication skills (a–c) and the Lyapunov exponent. One line indicates one subject.

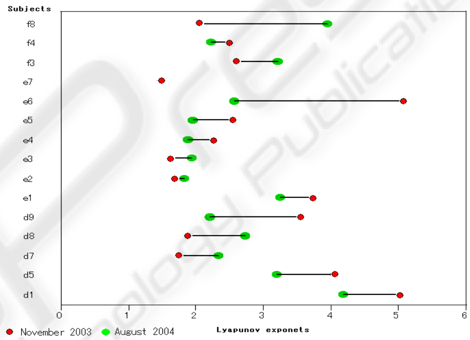

Figure 10: Results of the re-measurement of the Lyapunov exponent after 9 months (15 subjects). Subject e7 had died prior to the second measurement.

4.2 Case Studies of Maternal Attachment of Children

Subjects: Data were obtained from 242 children 0- to 5 years old from nurseries in Osaka and Himeji.

Date of measurement: January 2004–March 2005.

Measurement method: Fingertip pulse waves were measured twice for 1 min each.

Pulse waves were measured in a relaxed environment at 25ºC (room temperature). Within the age range of children tested, 3-year-olds had lower mean values in the largest Lyapunov exponent than ones of the other ages. There was a significant relation between mean values in the largest Lyapunov exponent and children ages ($p < 0.05$ using t-student test). Divergence was highest in 0-year-olds, followed by 1-year-olds and 2-year-olds, and was lowest in 3-year-olds (Fig. 11). For 3-year-old children, some widely held beliefs concerning their states and attachment seemed to correspond scientifically to the divergence of the attractor trajectory in pulse waves.

Table 2: Relation between the age and number of children.

	Males	Females	Total
0-year old	2	5	7
1-year old	13	10	23
2-year old	19	13	32
3-year old	27	27	54
4-year old	44	25	69
5-year old	34	23	57
Total	139	103	242

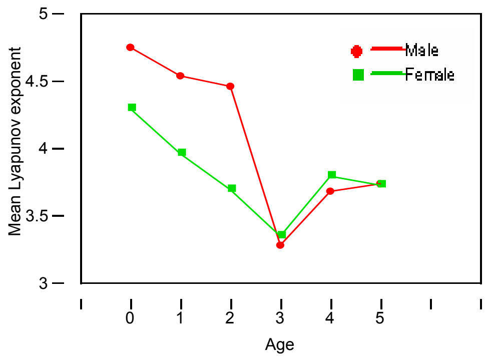

Figure 11: Relation between the Lyapunov exponent and the age of children (242 subjects).

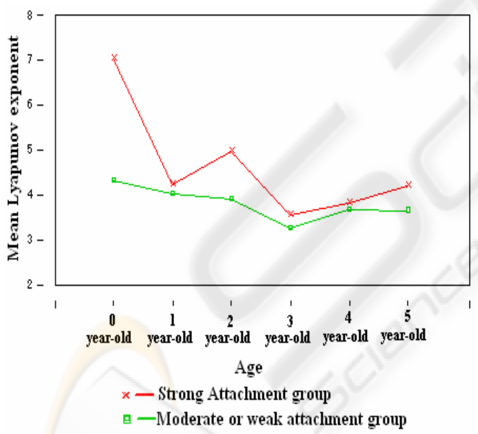

Figure 12: Relation between the Lyapunov exponent and maternal attachment to the child.

Additionally, questionnaires were completed by the mothers to study maternal attachment to the children (Index: Maternal Attachment Inventory MAI (Muller, 1994). After measurements were taken, the children were divided into two groups: a group with high maternal and a group with low maternal attachment. There was a significant relation between attachment and the Lyapunov exponent ($p < 0.05$ using t-student test; Fig. 12). These results indicate that problems of maternal attachment are also related to divergence in children, and could therefore be of help to mothers in child rearing.

4.3 Studies of Employees and the Tiredness Index

The Lyapunov exponents of 12 employees of a specific company were measured three times during the day: in the morning, immediately after arriving at the office; in the afternoon, 1 h after lunch; and in the evening, before leaving the office for the day. At the same time, the subjects were questioned to determine their tiredness index. We then examined the relation between the Lyapunov exponent and the tiredness index. Changes in the Lyapunov exponent with the time of day differed among the employees (Figure. 13). Because the management of mental health in business has caused many problems, including occurrences of depression, the Lyapunov exponent is a useful index not only for employees' self-management, but also for employers.

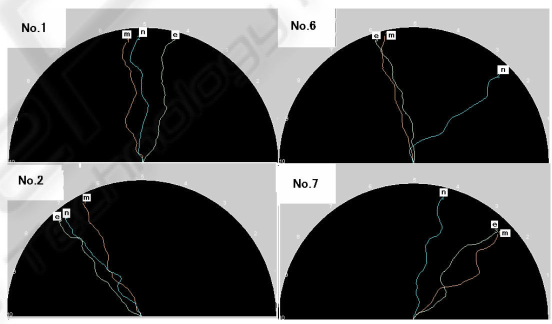

Figure 13: Changes in the Lyapunov exponents of employees of a specific company in the morning, afternoon, and evening.

The relation of the Lyapunov exponent to the tiredness index indicated that subjects with a low Lyapunov exponent in the afternoon tended to have depressive tendencies and strong anxiety (Table 3).

4.4 Experiments of Arithmetic Operations

Kraepelin tests that is addition work of numerical value were conducted twice for 15 min each on subjects in their 20s and 40s, and changes in the Lyapunov exponent were studied before and after the tests. The Lyapunov exponent increased in all subjects after the Kraepelin test. The subjects gave the impression that they felt better after the Kraepelin test than they did before the test (Fig. 14).

Table 3: Relation between the Lyapunov exponent in the afternoon and the tiredness index of employees. An inverse correlation greater than –0.7 means that a low Lyapunov exponent indicates a depressive tendency and a strong tendency toward anxiety.

	Willpower Decrement	Anxiety	State of Depression	Tiredness Accumulation	Lyapunov exponent Midday
Willpower Decrement	1	0.7235	0.7539	0.7496	-0.6385
Anxiety	0.7235	1	0.8455	0.9358	-0.7279
State of Depression	0.7539	0.8455	1	0.8420	-0.7014
Tiredness Accumulation	0.7496	0.9358	0.8420	1	-0.6305
Lyapunov exponent Midday	-0.6385	-0.7279	-0.7014	-0.6305	1

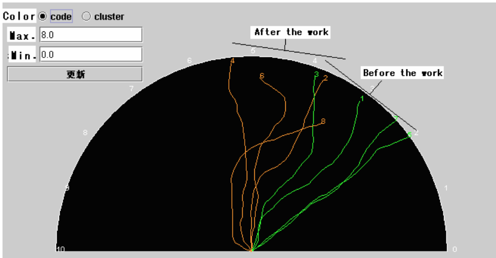

Figure 14: Changes in the Lyapunov exponent before and after the Kraepelin test.

4.5 Studies of Operation Error in Monitoring and Judgment Work

An apparatus used to simulate monitoring on a personal computer was developed to examine the relation between the Lyapunov exponent and the human error rate. The experiment was conducted by increasing the number of monitoring images from three to six, and then to nine images. In all cases, the error rate was high when the Lyapunov exponent was low (Figure. 15).

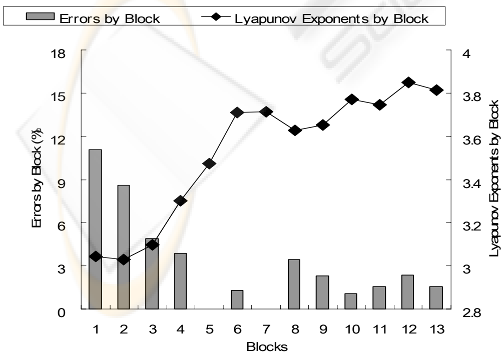

Figure 15: Relation between the Lyapunov exponent and human error rate in monitoring work over 30 min. Symbols and line indicate the Lyapunov exponent by block (3min); bars indicate the human error rates by block.

4.6 Studies of Painting Work

We measured the Lyapunov exponent when a certain artist did nothing and again 3 min after he began painting. The Lyapunov exponent increased while the artist painted (Figure. 16).

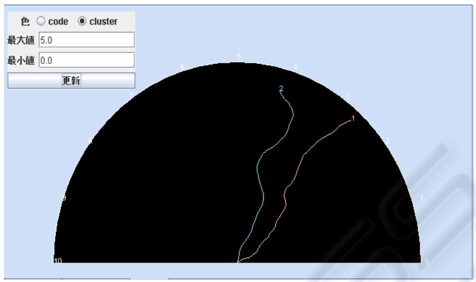

Figure 16: Changes in the Lyapunov exponent while painting. Orange, before painting; blue, during painting.

4.7 Studies of giving Birth Processes

The Lyapunov exponent was measured in seven pregnant women before and after giving birth (obstetrics and gynaecology in Nara city; Figure 17). Comparisons were made between the values measured within 1.5 h before birth and after birth. The Lyapunov exponent was significantly higher before birth than after birth (Student t-test, $p < 0.05$). Giving birth increased the functioning of the sympathetic nervous system.

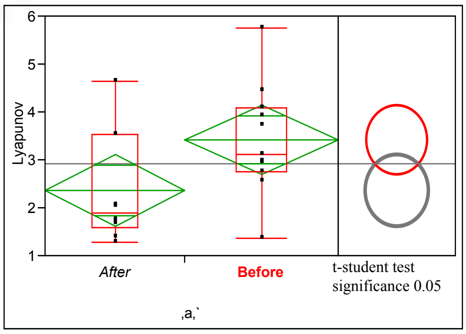

Figure 17: Comparison of the Lyapunov exponent measured in pregnant women within 1.5 h before and 1.5 h after giving birth.

5 SELF-CHECK SYSTEM

5.1 Equipment Components

A device that is easy to use and gives minimum burden on the subject is needed to measure the pulse waves. It is not possible to check the mental health of a person through just one round of measurements. For these reasons, the device must be convenient to use. We took note of the fact many people often do their work with PCs, and therefore developed a device that can make these measurements using a mouse. The pulse wave sensor is installed on one side of the pulse wave mouse; measurements can be made by simply touching the sensor with a finger. The mouse is connected to the PC through a USB port and can also be used as an ordinary mouse (patent pending).

Software installed on the PC starts and ends the measurements, and sets their duration.

5.2 Representation System using Constellation Graphs in Mental Health Self-Checks

Previous studies indicated the possibility of using the Lyapunov exponent as a new psychological index. However, as noted above, it is dangerous to judge mental health using only one measurement. Therefore, even over the period of a single minute, several measurements are necessary to assess daily fluctuations. It is also necessary to prepare a self-feedback system to determine when changes in the values of the Lyapunov exponent can be observed.

Figure 17: Example of a time series constellation graph for a self-diagnosis system. The right area of the graph indicates large Lyapunov exponents; the left area indicates small Lyapunov exponents. Changes among seven measurements are shown; circles indicate the standard deviation of the Lyapunov exponent for each measurement. If the point constitutes a change, the self-stated status at that point is shown.

To do this, a time series of the Lyapunov exponent must be recorded over several days and weeks to monitor natural variation, and the status of the pulse wave data should be recorded using simple words or keywords. To accomplish these measurements, the development of apparatus capable of taking measurements easily and of software that can indicate changes in mental health is necessary (Fig. 17).

5.3 Future Plan and Some Problems

There are three potential types of self-diagnosis system that use the divergence of fingertip pulse wave attractor. The first type is the personal computer (PC)-completed type, in which all operations from measurement to display are performed on one PC. In the second type, pulse wave data stored on a PC are transferred to a server via the Internet to construct a database. The software used to analyze the pulse waves on the server is either downloaded or pulse wave data are sent through the server. In the third type, a sensor for taking pulse wave measurements is installed on a cellular phone and the display of the results is provided as an image on the cellular phone. In this case, the Internet is also used. In the second and third types, results are accumulated in a database via the Internet, and a system is constructed for an available search. We expected that data will be accumulated through Internet use, enabling further advanced study. However, sufficient caution should be taken to protect the security of personal information.

If the self-management of mental health and early detection and treatment of diseases can be accomplished using this system, many people might be saved from terrible situations resulting from mental problems or instability. In addition, sending data regarding the mental indexes of humans using a network may lead to innovations in communication. However, sufficient care should be taken in the data management because of recent problems concerning the protection of personal information. However, in terms of the effectiveness in promoting further research, the accumulation of information would be extremely helpful for various future studies.

6 CONCLUSIONS

Mental management in humans is increasingly important as society continues to change. Accurate measurements have been difficult to obtain in the past using both subjective and objective methods, and the time and cost required to take brain measurements have imposed heavy burdens on patients. Measurement of pulse waves is simple and has the merit of imposing a comparatively minor burden on the subjects.

The complete realm of information obtainable from pulse waves has not yet been fully elucidated, but we have found that the information is deeply related to the behavior of the autonomous system networked throughout the body via the spinal cord from the part of the brain stem responsible for much of human activity and responses. The divergence of pulse waves is thought to be the value most related to the function of the nervous system, including the sympathetic and parasympathetic nerves that are integrated with the brain stem. In the future, we plan to further document these relations through various experiments.

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