Abstract — In this research, we investigated the relation between observers’ psychophysiological conditions and human errors made in the task of monitoring electrocardiogram (ECG) wave pattern changes. The number of errors and fingertip volume pulse waves were recorded during the task. Chaos analysis was applied to the fingertip volume pulse waves to calculate the largest Lyapunov exponents. The number of diagnostic errors of judgment and operation errors was treated as human errors. We found significant negative correlation between the largest Lyapunov exponents and human errors. The results showed that when the largest Lyapunov exponents were low, the observers made mistakes.

I. INTRODUCTION

A. Human Errors

The accidents occur frequently owing to human errors. For example, there are monitoring patients’ conditions in a clinical setting and monitoring instruments for air traffic control.

Fig.1 shows the change in the number of deaths in Japanese industrial scenes. The government revised the law about maintenance of industrial surroundings and the accidents decreased significantly in 1972. However, the events have hardly changed markedly, because human have had property of making mistake by nature. It is called “human errors”. That is to say, human errors trigger the accidents.

Some errors result from inappropriate environmental conditions, but far more errors are caused by human factors such as physical and mental fatigue.

B. The Relation Between Human and Chaos

Chaos analysis has been used for biological information since it suggested that heart or brain disease can be detected in the chaos analysis of blood flow [1]. It was proposed that a healthy body is full of chaos, and it is the source of life [2].

The characteristics of chaotic fluctuations (the largest Lyapunov exponents) of capillary vessels are different between normal subjects and psychiatric patients [3]. The chaotic fluctuations decreased in the state of sympathetic dominance and increased in the state of parasympathetic dominance among normal subjects. However, the chaotic fluctuations decreased in the symptomatic phase of psychiatric patients.

Uttered voice contains the chaotic fluctuations (the largest Lyapunov exponents). The variations in chaotic fluctuations of uttered voice are strongly related to the mental status of the person, and these exponents change according to the status of the brain functions of the person [4].

Fingertip volume pulse waves provide chaotic biological information, and time-series data on the largest Lyapunov exponents obtained by chaos analysis of fingertip volume pulse waves offer an index of adaptability to changes in the external environment and communication skills [5], [6]. Therefore, human conditions relate to biological information. Then we use fingertip volume pulse waves as index to grasp human psychophysiological conditions, because we can measure it easily.

C. Purpose

The purpose of this research is to verify the relation between observers’ psychophysiological conditions and human errors (errors of judgment and operation errors) measured by fingertip volume pulse waves during monitoring of a ECG pattern changes task.

Chaotic fluctuations, that is to say, the largest Lyapunov exponents were expected to be low when errors occurred.

II. METHOD

A. Observers, Date, Time, and Experimental Condition

Observers (participants) were 13 university students (6 males and 7 females), and aged 20 to 24 years (average age, 22.2 years). The experimenter introduced each observer (participant) about task in advance. This experiment was performed in a completely soundproof shielded experimental booth over a 17-day period from 13-29 November 2004. The temperature of the room was kept constant at 24 to 26°C, and the room was illuminated by artificial light (186 lx).
B. Apparatus

The Experimental Psychological System (see the following section “Monitoring Task”) developed was initiated [7], and stimuli (ECG waves) were displayed on a 19-inch computer monitor. Fingertip volume pulse waves were recorded using a fingertip/ear lobe pulse wave collector (BCU101, CCI Inc.). The largest Lyapunov Exponents were calculated using BACS Detector version 2.0.3.

C. Monitoring Task

This experiment was intended to simulate a clinical setting. Each observer monitored patients’ ECG waves displayed on the computer monitor. Fig.2 shows nine patients’ conditions. Each ECG wave show patients’ conditions and at first all patients were in a normal condition, but in some cases, they may get worse later than the normal condition. Patients’ ECG conditions changed in the chaotic way over time in five grades: normal state, slight abnormality, moderate abnormality, severe abnormality, and cardiac arrest (death).

The timing of ECG pattern changes was chosen so as to simulate human chaotic fluctuations so that patients’ conditions looked like real heart disease patients. Each patient was assigned to a different heart disease.

Fig.3 shows our experimental situation and the actual monitoring task. Photoplethysmography sensor was attached to observer’s left index finger, and the observer pressed the keyboard by right hand (see Fig.4).

D. Operational Procedure and Human Error

Fig.5 shows the flowchart of operational procedure and occurrence of human error.

1) The observer monitors patients’ conditions (ECG waves). Each observer assesses changes of the patients’ conditions.

2) In spite of the patients’ conditions being normal, the observer presses the numeric codes, and the patient’s condition changes “slight abnormality”. This is called “error of judgment”.

3) When the patients’ conditions change the abnormal state, if the observer can notice its, he/she must press the numeric codes. However if he/she can not notice its, it is “overlook”.

4) The observer can assess change of the patients’ condition, but if it is false discrimination, it calls “error of judgment” too.

5) Even though the observer’s judgment is correct or incorrect, the observer has to press the numeric codes. For example, if the numeric code is “273876”, the observer presses “273876” and a patient’s condition will recover normal state. The numeric code is supposed to be a medicine number which will be given for treatment.

6) When the numeric code is wrong, it is “operation error”. If the observer keeps mistaking the treatment, the patient dies.

7) When the numeric code is right, patient’s condition recovers to the normal state.

E. Procedure

There were three experimental conditions. Each observer monitored 3, 6, or 9 patients simultaneously in one condition and participated in all conditions (within-subjects design). Each condition lasted 40 minutes, and there was a 15 minutes interval between conditions. Total time of this experiment was about 3 hours.
For the time series data $x(i)$, with $i=1,\ldots, N$, obtained from the fingertip volume 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 delay, $\tau$, the vectors in the space are generated as $d$-tuple from the time series and are given by:

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

where $x_k(i) = x(i-(k-1)\tau)$, with $k=1,\ldots,d$. In order to reconstruct the phase space correctly, the parameters of the delay, $\tau$, and the embedding dimensions, $d$, should be chosen optimally [8]. For the time series recorded from human finger photoplethysmogram, we chose the parameters $\tau=50$ ms and $d=4$ [1] [2].

In the reconstructed phase space, one of the important measures of complexity is the largest Lyapunov exponent, $\lambda_1$. Consider $X(t)$, the evolution of some initial trajectory $X(0)$ in the phase space over time, given by:

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

Where

$$\delta X_\varepsilon(t) = X(t) - X_\varepsilon(t)$$
$$\varepsilon = X(0) - X_\varepsilon(0)$$

for almost all initial difference vectors $\varepsilon = X(0) - X_\varepsilon(0)$. We estimated $\lambda_1$ using the algorithm of Sano and Sawada [9]. $\lambda_1$ describes the divergence and instability of the orbits in the phase space.

The largest Lyapunov exponents, $\lambda_1$, were calculated for a basic window of 3,500 points. The 40 minutes (480,000 points) were covered by sequentially sliding 200 points (1 sec) at a time and $\lambda_1$ was determined for each window.

Fig.6 shows the flowchart from the measurement of photoplethysmograms to the calculation of Lyapunov exponents.

We prepared the attractors for four embedding dimensions from pulse wave data with chaotic characteristics and calculated the largest Lyapunov exponents, which reflect the divergence of the attractor trajectory [9].

The percentage of inappropriate treatments administered in response to changes in the patients’ conditions was calculated, and the result was defined as errors. Chaos analysis of the fingertip volume pulse waves was used to calculate the largest Lyapunov exponents. Each condition was divided into 13 blocks (blocks 1 to 12 were 3 minutes,
and block 13 was 4 minutes). The mean value of each variable was calculated for each block (hereafter referred to as errors by block and the Lyapunov exponents by block, respectively).

III. RESULTS

Fig. 7, 8, and 9 present the time course of errors and the Lyapunov exponents by block when observers monitored 3, 6, or 9 patients at the same time. The bar graphs represent errors by block, and the line graphs represent the Lyapunov exponents by block. The figures reveal a similar time course for the two variables. A correlation coefficient was calculated to assess the statistical relation between the two variables. There was a significant negative correlation between errors by block and the Lyapunov exponents by block under all conditions (3 patients condition: \( r(13) = -0.82, P < 0.001 \); 6 patients condition: \( r(13) = -0.77, P < 0.01 \); 9 patients condition: \( r(13) = -0.90, P < 0.001 \)).

IV. DISCUSSION

Errors were tended to be small when the Lyapunov exponents were greater, suggesting that the observers dealt flexibly with their experimental environment. In contrast, errors were high when the Lyapunov exponents were low. That is to say, the observers could not react to situational changes and they were in negative psychological states, like a mental fatigue and feelings of failure.

These results of this research suggest that the Lyapunov exponents can be used as an index of the psychophysiological condition of observers. Although we suspect that the changes in the value of the Lyapunov exponents were caused by within-subject factors, such as a sense of urgency and feelings of failure, it will be necessary to identify more precisely the cause for the changes in future studies.

We are assured that if the Lyapunov exponents decrease before the observer makes a mistake, we will be able to predict the occurrence of human errors.

REFERENCES

