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The Relationship between Fluctuation of Biological Signal: Finger Plethysmogram in Conversation and Anthropophobic Tendency

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***Abstract*—**Human biological signals (pulse wave and brain wave, etc.) have a rhythm which shows fluctuations. This study investigates the relationship between fluctuations of biological signals which are shown by a finger plethysmogram (i.e., finger pulse wave) in conversation and anthropophobic tendency, and identifies whether the fluctuation could be an index of mental health. 32 college students participated in the experiment. The finger plethysmogram of each subject was measured in the following conversation situations: Fun memory talking/listening situation and regrettable memory talking/ listening situation for three minutes each. Lyspect 3.5 was used to collect the data of the finger plethysmogram. Since Lyspect calculates the Lyapunov spectrum, it is possible to obtain the largest Lyapunov exponent (LLE). LLE is an indicator of the fluctuation and shows the degree to which a measure is going away from close proximity to the track in a dynamical system. Before the finger plethysmogram experiment, each participant took the psychological test questionnaire "Anthropophobic Scale." The scale measures the social phobia trend close to the consciousness of social phobia. It is revealed that there is a remarkable relationship between the fluctuation of the finger plethysmography and anthropophobic tendency scale in talking about a regrettable story in conversation: The participants (N=15) who have a low anthropophobic tendency show significantly more fluctuation of finger pulse waves than the participants (N=17) who have a high anthropophobic tendency ($F(1, 31) = 5.66$, $p<0.05$). That is, the participants who have a low anthropophobic tendency make conversation flexibly using large fluctuation of biological signal; on the other hand, the participants who have a high anthropophobic tendency constrain a conversation because of small fluctuation. Therefore, fluctuation is not an error but an important drive to make better relationships with others and go towards the development of interaction. In considering mental health, the fluctuation of biological signals would be an important indicator.

***Keywords*—**Anthropophobic tendency, finger plethymogram, fluctuation of biological signal, LLE.

I. Introduction

THE most basic activities of humans such as breathing [1], heart rate [2], and walking [3]-[5] are rhythmic phenomena. In the case of heart rate, the heart is undergoing a strong influence from the autonomic nervous system. The autonomic nervous system consists of the sympathetic and parasympathetic nerves, and each plays the role of the accelerator and the brake, respectively. The sympathetic nerve raises the heart rate in humans. On the other hand, the parasympathetic nerve reduces the heart rate. The parasympathetic nerve has the responsibility to change the heart rate depending on the circumstances, and quickly managing blood flow by identifying the intensity and state of mind or physical activity. In this way, heart rate is never regularly at the micro level [6]. Formerly, rhythm studies used to pay attention to stability; however, rhythm has a fluctuation with stability as well. The circadian rhythm is approximately 24 hours, and is fluid by nature. If this fluctuation capability did not exist, people would no longer recover from jet lag. Koori & Morita [7] pointed out that rhythm has the following two features: stability and responsiveness. Stability means the state of being stable; responsiveness means "being able to react quickly" and ability to make adjustments to new conditions or new information. Responsiveness is expressed as fluctuation in the biological signal. And fluctuation could be measured as the LLE. The Lyapunov exponent is a mathematical way of assessing a system's sensitive dependence on initial conditions by determining the rate of its divergence in phase space. The Lyapunov exponent of a dynamical system, such as a psychological system, is a quantity that characterizes the rate of separation of infinitesimally close trajectories [8]. Where λ is treated as the Lyapunov exponent, two trajectories in phase space with initial separation $\delta(0)$ diverge at a rate given by [9], [10].

$$\| \delta(t) \| \approx \| \delta(0) \| e^{\lambda t} \quad (1)$$

Usually the largest one as the LLE is adopted, because it determines a notion of predictability for a dynamical system. LLE is the divergence of the attractor trajectory and is an important value related to psychological indices [11].

It is known that there is a biological rhythm for human beings which can reflect the human mind. It is also known that the human mind is to change and develop through the interaction with others [12], [13]. Here, an important question arises in terms of human relationships. What happens when two rhythms meet? In other words, how do these two rhythms with fluctuations interact with each other in a communication situation where two people have a conversation? In the present study, this question will be approached using biological signals which are shown by the finger plethysmogram, commonly known as finger pulse wave. This study clarifies the psychological structure of human interaction and investigates

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the relationship between fluctuations of finger pulse waves in conversation and anthropophobic tendency which is an important feature for human interaction.

II. Method

A. Participants

Thirty-two college and graduate students (female 21; male 11) participated in this study. They were divided into pairs.

B. Situation

Four conversation situations between two (make/listen to fun or pleasant talk, make/listen to regrettable talk) were set for three minutes each, and the finger plethysmogram of each participant was measured. For the comparison, each participant was individually measured by a finger plethysmogram in a rest situation (without conversation) for three minutes.

C. Measuring Instrument

Lyspect 3.5 (Chaos Technology Research Laboratory: 200 Hz) was used as a measuring instrument for the finger plethysmogram.

D. Psychological Test

Before the above experiment, the participants were individually asked to respond to a psychological test questionnaire, Anthropophobic Scale [14], [15]. Anthropophobia or anthrophobia, also called interpersonal relation phobia or social phobia, is a pathological fear of people or human company. In short, it is said that anthropophobia is an extreme pathological form of shyness and timidity [16], which reflects people's irrational belief [17].

III. Results

Regarding the contents of the conversation, there were mainly two kinds of topics about human relations in club activities at high school (I enjoyed it very much because we made efforts to cooperate with each other. / I felt frustrated because I was portrayed as the villain when the members were divided by a confrontation.) and about entrance examinations (I was very happy when I passed the examination. / I felt frustrated because I failed the examination.).

A. Attractor Showing Rhythm and Fluctuations

Biological signals which are shown by finger pulse waves indicate each person's coherent rhythm and fluctuations. Using the technique of [18] who modified the Takens Embedding Theorem [19], the attractor can be shown in the phase space through a finger pulse wave. Here, although the Whitney Embedding Theorem [20] holds that a generic map from an n-manifold to 2n+1 dimensional Euclidean space is an embedding: The image of the n-manifold is unfolded in the larger space, [19] proved that instead of 2n+1 generic signals, the time-delayed versions $[y(t),y(t-\tau),y(t-2\tau),\ldots,y(t-2n\tau)]$ of one generic signal would suffice to embed the n-dimensional manifold, restricting the number of low-period orbits with respect to the time-delay τ and repeated eigenvalues of the periodic orbits [21].

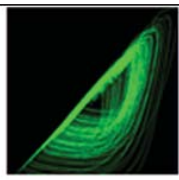
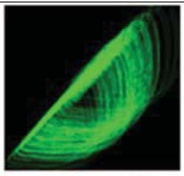
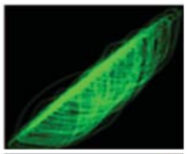
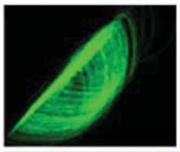
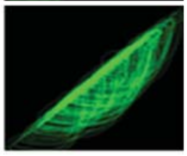
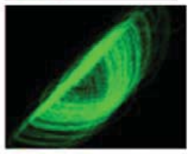
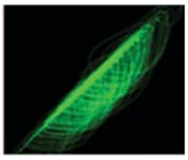
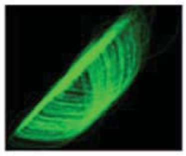
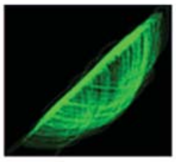
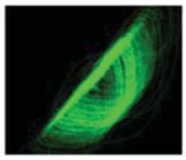
Participants	Odd	Even
Rest situation		
Conversation situation 1		
Conversation situation 2		
Conversation situation 3		
Conversation situation 4		

Fig. 1 Attractor in each situation of Pair A

Attractors of finger wave pulses in each situation of pair A are shown in Fig. 1. In conversation situation 1, participant Odd mainly talks about a fun story; participant Even listens. In conversation situation 2, participant Even mainly talks about a fun story; participant Odd listens. In conversation situation 3, participant Odd mainly talks about a regrettable story; participant Even listens. In conversation situation 4, participant Even mainly talks about a regrettable story; participant Odd listens. Each participant's attractor shows coherent rhythm and fluctuations. The similar shapes are iterated, and gradually, the shapes change. The similar shapes make a rhythm, and the change means fluctuations. Each participant's attractor is completely different in the rest situation; however, two persons' attractor is getting similar in the conversation situations.

B. LF/(LF+HF), HR, and LLE

Conventionally, activity of the sympathetic nerve has been shown in LF/(LF+HF) and LF/HF, since high frequency power (HF: 0.15 – 0.40 Hz) seems to reflect vagal activity to the heart, whereas low frequency power (LF: 0.04 – 0.15Hz) represents vasomotor activity and has been reported to reflect both sympathetic and parasympathetic modulation [22], [23]. It is suggested that the stability of LF/HF as indicator is poorer than LF/(LF+HF), because the denominator of LF/HF is only HF [24]. Thus, in this study, LF/(LF+HF) is used as the indicator of activity of the sympathetic nerve.

It is found that the activity of the sympathetic nerve in all situations is dominant since the scores of LF/(LF+HF) are bigger than 5 in Table I. Especially LF/(LF+HF) in conversation situations is bigger than LF/(LF+HF) in the rest situation (F (4, 124) =25.14, p<0.01). Furthermore, HR (Heart Rate) in the conversation situations is higher than HR in the rest situation (F (4, 124) =26.30, p<0.01). Moreover, LLE which is an indicator of fluctuation in the conversation situations is higher than LLE in the situation (F (4. 124) =14.54, p<0.01). Therefore, it could be considered that mental activity is much more active in the conversation situations than in the rest situation.

TABLE I
AVERAGE AND STANDARD DEVIATION OF LF/(LF+HF), HR, AND LLE

Situations	LF/(LF+HF) Average (SD)	HR Average (SD)	LLE Average (SD)
< Rest >	5.39 (1.82)	77.02 (10.51)	5.48 (1.46)
< Conversation >			
Talking: fun	7.33 (1.10)	85.70 (11.87)	6.91 (1.11)
Listening: fun	7.66 (1.03)	83.04 (11.30)	7.09 (1.16)
Talking: regret	7.05 (1.07)	87.72 (12.12)	6.98 (1.22)
Listening: regret	7.68 (0.90)	81.36 (10.28)	6.90 (1.18)

C. LLE and Anthropophobia

There is a negative correlation between LLE in the conversation situation of talking about a regrettable story and anthropophobia scale (*Pearson* r=-0.299), and LLE in the conversation situation of listening to a fun story (*Pearson* r=-0.215). There is almost no relation between LLE in the conversation of talking about a fun story (*Pearson* r=-0.074) and LLE in the conversation of listening to a regrettable story (*Pearson* r=0.013). As LLE is higher in situation of talking about a regrettable story, for instance, anthropophobic tendency is lower. Moreover, when participants talk about a regrettable story, the participants (N=15) who have a low anthropophobia tendency show significantly higher LLE than the participants (N=17) who have a high anthropophobia tendency (F (1, 30) =5.66, p<0.05). That is, the participants who show high LLE of biological signal in the situation of talking about a regrettable story tend to have a low anthropophobia tendency. More specifically, when the participants listen to a regrettable story, the LLE of high anthropophobic participants is also significantly lower than the LLE of low anthropophobic participants (F (1, 30) =5.11, p<0.05). When the participants listen to a fun or pleasurable story, the LLE of high anthropophobic participants is a little bit lower than the LLE of low anthropophobic participants, but it is not significant (F (1, 30)=3.71, p>0.05).

D. Cross Correlation of Pair in Conversation

The cross correlation of the pair in the conversation situations is shown in Table II. The number within the parenthesis is time-lag. One lag means 0.005 seconds. In conversation situation 1, odd-number participants mainly talk about a fun story; even-number participants listen to the story. In conversation situation 2, even-number participants mainly talk about a fun story; odd-number participants listen to the story. In conversation situation 3, odd-number participants mainly talk about a regrettable story; even-number participants listen to the story. In conversation situation 4, even-number participants mainly talk about a regrettable story; odd-number participants listen to the story. The highest absolute value of cross correlation is shown in Table II. The cross correlation of the biological signal is not high.

TABLE II
PLETHYSMOGRAM CROSS CORRELATION OF EACH PAIR IN CONVERSATION SITUATIONS

Pair	**Conversation Situations**			
	1	2	3	4
A	0.225 (7)	- 0.039 (5)	0.337 (5)	0.029 (3)
B	0.074 (- 5)	0.049 (- 7)	0.004 (7)	0.074 (- 7)
C	0.020 (7)	0.065 (7)	0.089 (3)	0.099 (- 7)
D	0.237 (- 7)	0.119 (- 7)	0.064 (0)	0.206 (- 7)
E	0.029 (2)	0.091 (4)	0.017 (7)	0.120 (- 7)
F	0.198 (6)	0.148 (- 7)	0.214 (0)	- 0.076 (5)
G	0.080 (- 6)	0.380 (0)	0.181 (7)	0.161 (7)
H	0.221 (6)	- 0.038 (- 3)	- 0.026 (- 4)	- 0.207 (88)
I	- 0.080 (- 7)	0.261 (7)	0.011 (- 5)	0.222 (- 7)
J	0.245 (7)	0.179 (- 7)	0.066 (7)	- 0.163 (4)
K	0.087 (3)	- 0.003 (- 5)	0.092 (6)	- 0.036 (- 7)
L	0.066 (- 6)	0.062 (- 6)	0.011 (- 7)	- 0.121 (49)
M	0.160 (- 3)	0.124 (- 7)	0.219 (6)	0.054 (- 5)
N	- 0.088 (0)	0.206 (- 7)	- 0.040 (- 2)	- 0.084 (- 7)
O	- 0.086 (7)	0.069 (6)	0.157 (- 6)	0.103 (- 5)
P	0.217 (0)	0.235 (- 5)	0.192 (5)	- 0.057 (6)

There are some components for whole biological signals which are shown by a finger plethysmogram; the components are heart rate, arteriovenous bloodstream, LLE, and so on. Therefore, the cross correlations of HR, LF/(LF+HF), and LLE of the pair are analyzed (LLE cross correlation is shown in Table III).

TABLE III
LLE CROSS CORRELATION OF EACH PAIR IN CONVERSATION SITUATIONS

Pair	**CONVERSATION SITUATIONS**			
	1	2	3	4
A	- 0.449 (- 2)	0.550 (7)	- 0.492 (- 33)	0.530 (-49)
B	- 0.524 (13)	- 0.477 (-53)	- 0.520 (10)	- 0.404 (-63)
C	0.379 (- 4)	0.734 (14)	- 0.402 (- 5)	- 0.574 (-37)
D	- 0.617 (16)	0.511 (- 5)	- 0.493 (44)	0.788 (0)
E	- 0.501 (5)	- 0.503 (89)	- 0.537 (55)	0.412 (-38)
F	0.471 (-31)	- 0.789 (11)	- 0.388 (59)	- 0.658 (10)
G	0.571 (8)	- 0.544 (66)	0.506 (-64)	- 0.493 (-30)
H	- 0.443 (98)	- 0.506 (65)	- 0.480 (38)	- 0.589 (29)
I	0.470 (2)	0.535 (-84)	0.499 (-25)	- 0.498 (19)
J	- 0.610 (10)	- 0.634 (10)	0.419 (3)	- 0.490 (30)
K	- 0.619 (-28)	- 0.733 (19)	- 0.259 (71)	- 0.292 (-87)
L	- 0.549 (55)	- 0.643 (5)	- 0.475 (-39)	- 0.692 (20)
M	- 0.411 (-31)	0.425 (-33)	- 0.347 (33)	- 0.526 (-70)
N	- 0.505 (95)	- 0.514 (-18)	0.402 (-39)	0.525 (5)
O	0.471 (-47)	- 0.488 (43)	- 0.644 (62)	- 0.328 (- 5)
P	0.618 (- 1)	- 0.265 (-60)	- 0.377 (51)	- 0.591 (18)

Even though the cross correlation of the finger pulse wave is not remarkably high, the cross correlation of HR, LF/(LF+HF), and LLE, which are the components of the finger plethysmogram, is very high (HR: -0.847(0) to 0.919(-1);

LF/(LF+HF): -0.890(26) to 0.818(-46); LLE: -0.789(11) to 0.788(0)).

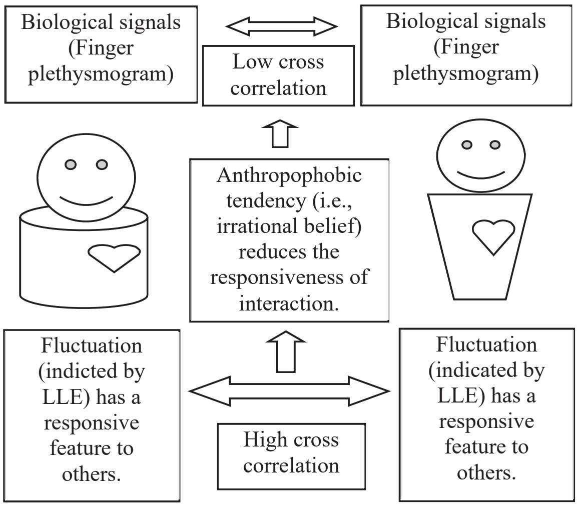


Fig. 2 Mental structure which is shown by biological signals in conversation situations

IV. Discussion

It is found that human beings have rhythmic biological signals and fluctuations which are shown by attractors in a phase space using a finger plethysmogram in this study. Fluctuations, which are indicated by LLE, are not an error but very important for human beings to live, because fluctuations are related to responsiveness, which is the ability to make adjustments to new conditions or new information. Human mental activity is very active in conversation situations; moreover, the participants who have a high fluctuation (i.e., high LLE) show a low anthropophobic tendency in the situation of talking a regrettable story. The fluctuation of biological signals could be an indicator of mental health for human interaction.

In the conversation situations, the most basic activities of human beings, such as HR, LF/(LF+HF), and LLE, show a high cross correlation of the two; biological signals as the whole, which are shown by pulse waves, express a low cross correlation. Therefore, it is considered that human beings have a tendency to entrain or synchronize with others basically or evolutionally; however, they have some experience with others and have learned about human relations a lot after birth. The experience makes up schema or a belief system, especially irrational belief [17] for human interaction. Their schema or belief system for human interaction, which is indicated by anthropophobic tendency in this study, reduces the basic activity of entrainment with others (see Fig. 2).

It is said that the feedback delays of auditory-motor and visual sensory-motor systems are 100-300 milliseconds [25]. However, the synchronization phenomenon of biological signals, which are shown by a high cross correlation in the conversation situation, did not occur after conversation partners understood what the other person said. Rather, mental interaction occurred in a very short time (see Tables III & III). The participants share the atmosphere of the conversation, that is, their conversation schema is activated by keywords and their partner's attitude, and they infer what their partner would say. Therefore, it is considered that human beings use a feedforward mechanism rather than a feedback mechanism in a conversation situation. Biological signals reflect such mental activity of humans.

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