# Chaotic Changes in Fingertip Pulse Waves during Autobiographical Memory Retrieval

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Abstract: The effects of autobiographical memory retrieval on a psychophysiological index were examined. The experimental (retrieval) group conducted an autobiographical memory retrieval task, whereas the control group repeatedly vocalized Japanese syllabary. The largest fingertip pulse-wave Lyapunov Exponent (LLE) in chaos analysis, which is a nonlinear analysis, was measured as an objective psychophysiological index. Moreover, participants responded to a psychological questionnaire and completed an original checklist before and after the experiment. The results indicated that fingertip pulse-wave LLE increased significantly only in the retrieval group. This result supported previous findings that psychotherapies such as reminiscence therapy have positive effects on cognitive functions at the psychophysiological level. Moreover, only the retrieval group showed significant improvements in psychological indices. Therefore, recalling autobiographical memories and verbally sharing it with others might contribute to maintaining mental health. To date, autobiographical memory retrieval and reminiscence therapy have not been sufficiently examined by using physiological indices. This study's results using a physiological index are expected to contribute to research on reminiscence therapy.

## 1 INTRODUCTION

Japan's population is rapidly aging, and various countermeasures have been taken, including medical care, welfare, and economics, among others. The proportion of people aged 65 or older is called the "aging rate." If a society's aging rate exceeds 21%, it is called a super-aging society. The National Institute of Population and Social Security Research estimates that the aging rate is increasing, whereas the total population is decreasing in Japan. Therefore, Japan has become the first super-aging society globally, and it is estimated that the aging rate will reach approximately 30% in 2025 (Ministry of Internal Affairs and Communications, 2013). The aging society is an urgent issue, and problems related to elderly adults, including medical and welfare problems, need to be managed. Dementia, which is a general term that covers various disorders leading to disturbances in life, caused by a decline in intellectual functions, is a severe health problem of older adults. The core symptoms of dementia include memory loss, abstract thinking and judgment disorders, apraxia, agnosia, aphasia, and executive function disorders.

Reminiscence therapy has been used to prevent dementia, improve cognitive functions, and prevent deterioration of symptoms. It is an interpersonal assistance method and became become popular after Butler's publication in 1963. The basic concept of reminiscence is that a person's cognitive functions improve by talking about nostalgic memories with others. Tsuda (2015) introduced group reminiscence therapy with older adults living in a group home for dementia people and assessed residents and nursing care staff's changes. The results indicated an increase in many items in the observation scale score, including the N-ADL. On the other hand, Tadaka et al. (2005) reviewed previous reminiscence studies conducted with elderly participants with dementia and suggested that preceding studies were not always based on a definite criterion and that the essential effectiveness and significance of reminiscence have not been established to date, although findings support the efficacy of reminiscence to a certain extent. Sufficient empirical research on the effects of reminiscence using physiological indices has not been conducted to date.



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### 1.1 Chaos

At the end of the twentieth century, terms such as “Chaos”, “Fractals”, and “Complex systems” got much attention in the field of science. Chaos, as academic jargon, in general terms does not mean, “Disordered”. Chaos might be the order with a dynamic fluctuation. According to Aihara(1993), chaos is “a phenomenon with very complicated, irregular, and unstable behaviors because of the nonlinearity of the system, although the system is following deterministic laws, and it is impossible to predict the future state.” Chaos might be expressed as a “fluctuation” to facilitate understanding. Many natural and biological phenomena are complex systems that fluctuate with chaos. For example, fingertip pulse waves, which are biosignals, including information of the central nervous system, and the autonomic nervous system, among others, are considered chaotic phenomena. Chaos analysis is a nonlinear time series analysis that quantifies the strength of chaos, and objectively recognizes the psychosomatic state by extracting information that cannot be obtained through linear analysis (Imanishi & Oyama,2008). The fluctuation is expressed by quantitative values such as Largest Lyapunov Exponent (LLE), which is a quantification of sensitivity to the initial conditions, which is one of the characteristics of chaos. Many researchers have indicated a correlation between a chaotic fluctuation expressed by LLE of biological information and mental and physical health. The external adaptability declines, and physical and mental health cannot be maintained when a low level of LLE continues, i.e., when a non-fluctuant condition continues over time. It has been indicated that the attractor of patients with depression or dementia has low fluctuations, and the LLE is reduced. When depression advances, LLE becomes further decreases (Oyama, 2012). Imanishi, Shiomi, & Oyama (2009) and Oyama (2012) reported that LLE of fingertip pulse waves declined when an excessive mental and physical load was applied to participants, suggesting that LLE of fingertip pulse waves is correlated with mental and physical health. The above findings suggest that LLE, which is biological data, might be deeply correlated with mental and physical health. The fingertip pulse wave LLE is a useful and objective index that correlates with mental and physical health. Moreover, fingertip pulse waves can be measured easily using a fingertip cuff and need only 1-2 minutes for a completed measurement, which is a non-invasive method that places a low physical and mental burden on participants.

### 1.2 Purpose

As described above, it is necessary to use objective indices in reminiscence studies. Efficiently assessing reminiscence therapy's effects using objective indices through chaos analysis of fingertip pulse waves would contribute to further development of reminiscence therapy and provide a useful measure for managing different older adults' problems in a super-aging society. However, previous studies have not correlated reminiscence with LLE of fingertip pulse waves. In reminiscence therapy, autobiographical memories are shared between clients or between the client and therapist, which is expected to affect clients’ emotions and self-cognition. The present study examined the effects of recalling autobiographical memories and verbally sharing them with others on LLE of fingertip pulse waves. Moreover, reminiscence therapy is expected to improve cognitive functions and relieve depression (Arean et al., 1993). Therefore, psychological indices were assessed before and after the experiment examining the psychological changes resulting from recalling autobiographical memory. In this study, we conducted preliminary experiments on university students, not elderly people.

## 2 METHODS

The experiment was conducted from October to December of 2018. Participants (N=18) were recruited using snowball sampling at A university located in Tokyo. Two participants with missing data were excluded, and the data of 16 participants were analyzed. The mean age of female participants (N=10) was 21.10 (*SD*=0.99) years, and that of male participants (N=6) was 21.83 (*SD*=1.72) years. They participated in the experiment twice; (1) conducting an autobiographical memory recall task (retrieval group), and (2) conducting a vocalizing Japanese syllabary task (control group). The tasks were performed in random order to counterbalance order effects. The second experiment was conducted after an interval of one or more days.

### 2.1 Equipment, Materials, Psychological Scales

Fingertip pulse waves were measured as a biological index by connecting a cuff sensor to a Lyspect 3.5 computer. The data were analyzed using a laptop computer. The time-series data were sampled at a frequency of 200 Hz for 180 sec. The time-delay was set at 10.0msec, and the embedding dimension (d) was set at 4, after Sano & Sawada (1985).

The participants also responded to the POMS 2 Japanese version for Adults (Yokoyama, 2015) and completed an original check sheet developed for this study after the intervention. POMS2 is composed of seven subscales; Anger-Hostility, Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, Tension-Anxiety, Vigour-Activity, and Friendliness. Responses to POMS 2 are made using a 5-point scale ranging from 1 (Never) to 5 (Very often). The participants were required to respond to how they currently felt. The original check sheet developed for this study included items inquiring participants' childhood memories and whether they could talk appropriately during the experiment. The control group participants were given a Japanese syllabary that was printed on an A4 paper.

## 2.2 Procedures

First, participants were instructed, "Please choose the most appropriate option for describing your current feelings without thinking too deeply." They responded using the POMS 2 Japanese version for Adults (Yokoyama, 2015). Then, the participants were instructed, "We will measure your fingertip blood flow for three minutes. Please put the cuff around your right index finger and do not move during the measurement. Please take a comfortable position, breathing easily without closing your eyes, and be natural." After the instructions, the participant's fingertip pulse waves at rest were measured for three minutes (Retrieval, pre; Control, pre). Next, the control group repeatedly read the Japanese syllabary aloud while their finger pulse waves were measured simultaneously (Control, midst). The control group was instructed, "Please slowly read aloud the Japanese syllabary written on the paper, without considering the pronunciation or voice volume. The measurement was conducted for three minutes. Please restart from the beginning after you reach the end of the syllabary." The retrieval group was instructed, "Please talk about the happiest memory of your childhood. Please notify me when you have finished describing it." The fingertip pulse waves were simultaneously measured (Retrieval, midst). Next, LLE was measured again for three minutes in both groups (Retrieval, post; Control, post). After the measurement, the participants again responded to POMS 2. Only the retrieval group was requested to complete the original check sheet after POMS 2. They were instructed, "Please check the items that apply to you about the talk you just made and respond to the following questions."

## 2.3 Ethical Considerations

Participants were instructed that they could quit the experiment even in the middle for any reasons and that they would incur no disadvantages for not responding, quitting the experiment, or based on the content of their responses. Moreover, they were explained that the experimental results would be statistically processed and used only for academic purposes and that the data would be stored in a USB memory stick that has been encrypted. They were also told that no individuals would be identified from the data. The participated took part in the experiment after giving their consent to the explanation.

## 2.4 Analytical Method

The original check-sheet was excluded from the analysis. Firstly, a one-way analysis of variance (ANOVA) was conducted to examine whether there was a significant difference ($p<.05$) between the two groups (retrieval and control) before the intervention (pre), which indicated no significant differences. Next, the main effects of the group, and repetition and interactions between them were analysed. Descriptions of the main effects are omitted, and only significant or relatively effective interactions are described. Finally, a simple main effects test was conducted.

# 3 RESULTS

## 3.1 2x3 ANOVA on LLE Changes in the Two Groups

Table 1 shows the mean LLE, standard error, standard deviation, and 95% confidence interval for the two groups. A 2x3 ANOVA was conducted on LLEs of Control (pre, midst, post) and Retrieval (pre, midst, post) groups to examine for significant differences in the mean fingertip pulse wave LLE in autobiographical memory recall and control groups. The result is shown in Figure 1, indicating a significant difference in the mean LLE between Control midst and Retrieval midst and between Control post and Retrieval post groups. Moreover, the mean LLE increased in the retrieval group from pre to midst, and from pre to post. The mean LLE increased significantly only when recalling autobiographical memories (Table 2).

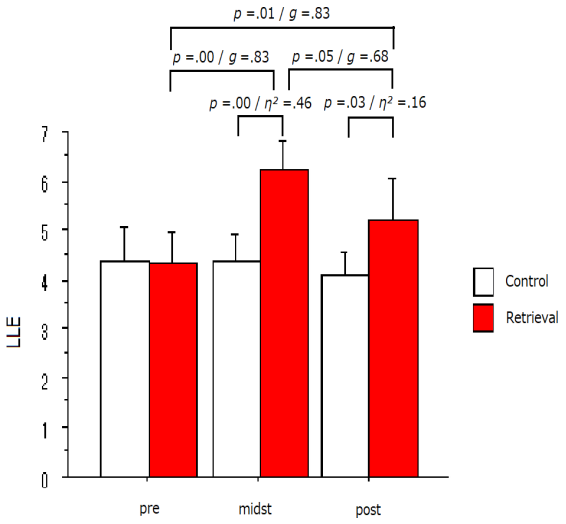


Figure 1: 2x3 ANOVA on LLE changes in the two groups.

## 3.2 ANOVA on Pre- and Post-experiment Changes in Psychological Indices

Table 3 shows POMS 2 fundamental statistics for Anger-Hostility, Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, Tension-Anxiety, Vigour-Activity, and Friendliness subscales. A 2x2 ANOVA was conducted with group and repetition as independent and POMS 2 subscale scores as dependent variables (Table4). The results indicated significant interactions or effective effect sizes for all the dependent variables. Therefore, a simple main effect test was conducted, which indicated a significant main effect of repetition in the retrieval group for Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, and Tension-Anxiety with "post" score significantly lower than the "pre" score in the retrieval group. These results indicated that depression, dejection, fatigue, inertia, tension, and anxiety decreased significantly only in the retrieval group.

Table 1: Basic statistics.

| *N*=16 | *Mean* | *SD* | *SE* | 95%CI Lower | 95%CI Upper |
|---|---|---|---|---|---|
| Control pre | 4.39 | 1.25 | 0.31 | 3.73 | 5.06 |
| Control midst | 4.35 | 1.02 | 0.25 | 3.81 | 4.89 |
| Control post | 4.10 | 0.90 | 0.23 | 3.62 | 4.58 |
| Retrieval pre | 4.31 | 1.20 | 0.30 | 3.67 | 4.95 |
| Retrieval midst | 6.22 | 1.07 | 0.27 | 5.65 | 6.80 |
| Retrieval post | 5.19 | 1.60 | 0.40 | 4.33 | 6.04 |

Table 2: ANOVA of the mean LLE for both groups.

| | *F* | *p* | $\eta^2_p$ | Result・Multiple comparisons(Holm) |
|---|---|---|---|---|
| Interaction | 10.80(2, 60) | <.001 | .21 | |
| Main effect pre | .04(1, 30) | .85 | .00 | |
| Main effect midst | 25.69(1, 30) | <.001 | .46 | Control＜Retrieval |
| Main effect post | 5.61(1, 30) | .03 | .16 | Control＜Retrieval |
| Simple main effect(Contlol) | .80(2, 30) | .46 | .05 | |
| Simple main effect(Retrieval) | 15.96(2, 30) | <.001 | .52 | pre<midst($t$(14)=5.35, $p$=.00, $g$=1.34) |
| | | | | pre<post($t$(14)=3.32, $p$=.01, $g$=.83) |
| | | | | midst>post($t$(14)=2.71, $p$=.02, $g$=.68) |

## 3.2 Anova on Pre- and Post-experiment Changes in Psychological Indices

Table 3 shows POMS 2 fundamental statistics for Anger-Hostility, Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, Tension-Anxiety, Vigour-Activity, and Friendliness subscales. A 2x2 ANOVA was conducted with group and repetition as independent and POMS 2 subscale scores as dependent variables (Table4). The results indicated significant interactions or effective effect sizes for all the dependent variables. Therefore, a simple main effect test was conducted, which indicated a significant main effect of repetition in the retrieval group for Confusion-Bewilderment, Depression-Dejection, Fatigue-Inertia, and Tension-Anxiety with "post" score significantly lower than the "pre" score in the retrieval group. These results indicated that depression, dejection, fatigue, inertia, tension, and anxiety decreased significantly only in the retrieval group.

Table 3: POMS 2 fundamental statistics.

| Control(pre) | | | | | |
|---|---|---|---|---|---|
| *N*=16 | *Mean* | *SD* | *SE* | 95%CI Lower | 95%CI Upper |
| Anger-Hostility | 7.44 | 4.26 | 1.06 | 5.17 | 9.71 |
| Confusion-Bewilderment | 9.81 | 4.34 | 1.08 | 7.50 | 12.12 |
| Depression-Dejection | 8.38 | 4.57 | 1.14 | 5.94 | 10.81 |
| Fatigue-Inertia | 10.25 | 4.11 | 1.03 | 8.06 | 12.44 |
| Tension-Anxiety | 9.81 | 3.87 | 0.97 | 7.75 | 11.87 |
| Vigour-Activity | 11.88 | 5.52 | 1.38 | 8.93 | 14.82 |
| Friendliness | 16.38 | 3.93 | 0.98 | 14.28 | 18.47 |
| Control(post) | | | | | |
| *N*=16 | *Mean* | *SD* | *SE* | 95%CI Lower | 95%CI Upper |
| Anger-Hostility | 6.19 | 2.07 | 0.52 | 5.08 | 7.29 |
| Confusion-Bewilderment | 6.19 | 4.14 | 1.03 | 3.98 | 8.39 |
| Depression-Dejection | 8.25 | 4.89 | 1.22 | 5.64 | 10.86 |
| Fatigue-Inertia | 9.94 | 3.43 | 0.86 | 8.11 | 11.77 |
| Tension-Anxiety | 9.50 | 3.43 | 0.86 | 7.67 | 11.33 |
| Vigour-Activity | 11.06 | 5.13 | 1.28 | 8.33 | 13.80 |
| Friendliness | 15.63 | 3.76 | 0.94 | 13.62 | 17.63 |
| Retrieval(pre) | | | | | |
| *N*=16 | *Mean* | *SD* | *SE* | 95%CI Lower | 95%CI Upper |
| Anger-Hostility | 7.88 | 4.30 | 1.08 | 5.58 | 10.17 |
| Confusion-Bewilderment | 11.06 | 3.40 | 0.85 | 9.25 | 12.87 |
| Depression-Dejection | 8.63 | 2.36 | 0.59 | 7.37 | 9.88 |
| Fatigue-Inertia | 10.44 | 3.24 | 0.81 | 8.71 | 12.17 |
| Tension-Anxiety | 9.88 | 3.26 | 0.82 | 8.14 | 11.61 |
| Vigour-Activity | 12.38 | 4.63 | 1.16 | 9.91 | 14.84 |
| Friendliness | 17.56 | 4.27 | 1.07 | 15.29 | 19.84 |
| Retrieval(post) | | | | | |
| *N*=16 | *Mean* | *SD* | *SE* | 95%CI Lower | 95%CI Upper |
| Anger-Hostility | 6.38 | 1.82 | 0.46 | 5.40 | 7.35 |
| Confusion-Bewilderment | 8.69 | 3.16 | 0.79 | 7.01 | 10.37 |
| Depression-Dejection | 7.38 | 2.22 | 0.55 | 6.19 | 8.56 |
| Fatigue-Inertia | 8.94 | 3.11 | 0.78 | 7.28 | 10.59 |
| Tension-Anxiety | 8.25 | 2.35 | 0.59 | 7.00 | 9.50 |
| Vigour-Activity | 11.94 | 4.58 | 1.15 | 9.50 | 14.38 |
| Friendliness | 16.56 | 4.70 | 1.18 | 14.06 | 19.07 |

Table 4: Results of analysis of variance of psychological indicators.

| | | *F* | *p* | $\eta^2$ |
|---|---|---|---|---|
| Confusion -Bewilderment | Interaction | 18.63(1,30) | <.001 | .31 |
| | Main effect pre | .82(1,30) | .37 | .03 |
| | Main effect post | 1.12(1,30) | .30 | .04 |
| | Simple main effect(Contlol) | .60(1,15) | .45 | .04 |
| | Simple main effect(Retrieval) | 21.24(1,15) | <.001 | .59 |
| Depression -Dejection | Interaction | 4.55(1,30) | .40 | .11 |
| | Main effect pre | .04(1,30) | .85 | .00 |
| | Main effect post | .43(1,30) | .52 | .01 |
| | Simple main effect(Contlol) | .32(1,15) | .58 | .02 |
| | Simple main effect(Retrieval) | 6.82(1,15) | .02 | .31 |
| Fatigue -Inertia | Interaction | 2.33(1,30) | .14 | .06 |
| | Main effect pre | .02(1,30) | .89 | .00 |
| | Main effect post | .75(1,30) | .40 | .02 |
| | Simple main effect(Contlol) | .46(1,15) | .51 | .03 |
| | Simple main effect(Retrieval) | 5.75(1,15) | .03 | .28 |
| Tension -Anxiety | Interaction | 3.36(1,30) | .08 | .08 |
| | Main effect pre | .00(1,30) | .96 | .00 |
| | Main effect post | 1.45(1,30) | .24 | .05 |
| | Simple main effect(Contlol) | .38(1,15) | .55 | .03 |
| | Simple main effect(Retrieval) | 10.26(1,15) | .01 | .41 |

# 4 DISCUSSION

The results indicated that participants' psychological conditions only improved when recalling autobiographical memories. Moreover, the mean LLE increased significantly, which suggested that fingertip pulse wave LLE significantly increases when recalling autobiographical memories and verbally sharing them with others.

As described above, fingertip pulse waves, which are biosignals, are considered chaotic phenomena that include information about the central nervous system and the autonomic nervous system. Therefore, chaotic pulse wave phenomena include physiological signals and information related to psychological conditions, such as feelings, emotions, and cognitive functions. Suzuki & Suzuki (2007) measured fingertip pulse waves of older adults with dementia before and after painting a picture, which indicated that the dynamic structure of chaos attractors was significant after their cognitive functions were stimulated by painting. Moreover, Oyama (2012) indicated that LLE decreased when communication skills decreased or dementia progressed, and low LLE continued depressed people. Consistently with the previous studies, the present study indicated that participants' LLE increased significantly when their psychological condition turns positive as a result of recalling and sharing autobiographical memories.

The results of this study suggest that psychological indices can be improved by recalling autobiographical memories. Takahashi & Matsuo (2007) examined pre- and post- autobiographical memory recall changes in 69 university women's emotions and reported a significant decrease in post-recall negative emotions. Moreover, Kobayashi, Iwanaga ,& Ikuwa (2002) suggested that autobiographical memories would be strongly recalled when feeling very nostalgic, and participants would develop positive feelings. The above studies have suggests that mental health can be maintained by interventions using autobiographical memory retrieval, which was supported by the present study.

Based on the above findings, it is suggested that the effects of psychotherapy, including reminiscence, i.e., recalling autobiographical memories and verbally interacting with others, can be measured by using LLE. The fingertip pulse wave measurement used in the current study is a non-invasive method that places a low physical and mental burden on participants because the equipment is easy to use, and the measurement needs only a short time. Although wearing a cuff around the fingertip might disturb daily life movements, pulse waves can also be measured at the earlobes. Empirical research using physiological indices are required for examining the effects of reminiscence. Using fingertip pulse waves LLE as an index could facilitate the easy assessment of reminiscence's temporary and long-term effects. In the future, different physiological indices should be used to assess the effects of reminiscence.

This study examined the effects of autobiographical memory retrieval on fingertip pulse waves LLE in healthy university students. However, it is unknown if the results would be similar when using reminiscence with older adults or dementia patients. In the future, the correlation between communication skills or cognitive functions and fingertip pulse waves LLE should be examined with older adults and patients with dementia to examine the effectiveness of fingertip pulse waves LLE as an objective index of cognitive functions. Moreover, the control group's task in the present study was vocalizing Japanese syllabi, which is rather monotonous. In the future, chaotic fluctuations in fingertip pulse waves LLE when talking about topics that are not associated with autobiographical memory retrieval should be compared to examine the meaning and functions of reminiscence in detail. The accumulation of such studies would contribute to the development of research on psychotherapy effects, including reminiscence associated with autobiographical memory retrieval. Also, studies on dementia, improvement in cognitive functions, and prevention of symptom deterioration could benefit from such research.

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