Analysis of Electrogastrograms of Elderly Subjects using the Double-Wayland Algorithm

Hiroki Takada† and Yasuyuki Matsuura

Graduate School of Engineering, University of Fukui
3-9-1 Bunkyo, Fukui 910-8507, Japan
Email: †takada@u-fukui.ac.jp

Abstract– It is difficult to distinguish between the electrogastrograms (EGGs) of healthy elderly individuals and elderly patients by using spectral analysis. The purpose of this study was to determine the feasibility of applying a complex dynamic analysis method to the EGGs of healthy young and healthy elderly male individuals. We analyzed EGGs by using the Double –Wayland algorithm, which is one of the indices of the stochastic characteristics of time series. For most of the temporal intervals, there were significant differences between translation errors estimated from the EGGs of the young and elderly individuals.

1. Introduction

The elderly suffer from gastrointestinal diseases such as constipation and functional gastrointestinal tract disturbance including gastroesophageal reflux (reflux esophagitis). Percutaneous electrogastrograms (EGGs) non-invasively and easily measure gastrointestinal activities.

The first recording of electric activity on the body surface was made by Alvarez in 1921, and he termed it an EGG [1]. EGGs were easily affected by electrocardiograms (ECGs) and electromyograms (EMGs) of the diaphragm during breathing due to the low induced potential from the abdominal wall. There was also no clear association with gastric activity and data analysis methods, and therefore they did not lead to clinical applications like ECGs and electroencephalograms.

There is regular electrical activity (EA) in the stomach and small intestine, as in the heart, and electric depolarization and repolarization are repeated. A pacemaker for gastric EA exists in 1/3 of the greater curve of the gastric body, and EA travels to the pyloric area 3 times per minute (3 cpm, cycles per minute) in humans. The pacemaker triggers periodic electrical activity controlled by the vagus nerve. This involves a cell group network called the interstitial cells of Cajal (ICCs) [2–4].

The advantages of EGGs are their utility in measuring the above-mentioned periodic electric activity and evaluating digestive autonomic nerve function. In the stomach of resting healthy individuals, peristalsis occurs 3 times per minute when a certain period of time has passed after meals [2–4]. The normal range of the EGG fluctuation cycle is between 2.4–3.6 cpm, but there is no clear standard except for a frequency close to 3 cpm [5, 6].

EGG studies have made progress with recent improvements in measurement technology. The common EGG analysis method is a spectral analysis technique such as Fast Fourier Transform (FFT), and few reports are available on non-linear analysis. However, when considering complex organic activity, non-linear analysis methods, including chaos analysis and evaluation based on stochastic process analysis, are considered inevitable for modeling of dynamic movement, an accurate diagnostic index, and extraction of a body assessment index.

The maximum Lyapunov exponent (MLE) is a common index of non-linear analysis [7, 8], and has been widely used in various fields, including economic modeling and sound analysis [9–11]. In biosignal analysis, biosignals are considered to be generated based on non-linear dynamic systems with a few degrees of freedom in the pulse and brain waves, and in the R–R interval of ECGs. Therefore, chaos analysis is used in these analyses [12–13]. In contrast, few reports are available on the chaos analysis of EGGs using the Lyapunov exponent. EGGs of the healthy young and healthy elderly individuals were compared using the MLE, which is an evaluation method of time-series chaos as a basic examination of the application of a non-linear analysis method to EGG [14]. There was a significant difference in MLEs estimated from EGGs of the healthy young and healthy elderly individuals with respect to time. There is therefore the potential for EGG classification of healthy elderly individuals based on the MLE distribution.

The Wayland algorithm has been improved in order to evaluate the degree of determinism for dynamic variables that generate a time series [15]. This algorithm has been applied to the analysis of the signals in railways, stock prices, and stabilometry.

There have been some studies concerning dynamic analysis using EGG, e.g., forward and inverse problems simulated using a three-dimensional model and computer simulations [14, 16–17]. However, no studies analyzing non-linear modeling are available. The aim of this paper is to estimate the dynamics that generate EGG based on a Double-Wayland algorithm. Non-linear characteristics of the EGG signal are estimated by this analysis.

2. Materials and Methods

2.1. Participants

Subjects were 7 healthy young males aged between 21 and 25, 7 healthy elderly males aged between 65 and 76 years with more than two-third of their stomach resected. Informed consent was obtained from each subject prior to the experiment. The research on young individuals was approved by the Ethics Committee, Nagoya City University Graduate School of Natural Sciences, and the research on healthy elderly was approved by the Ethics Committee of Aichi Medical University.

2.2. Materials

EGG measurement was performed using unipolar induction. The measurements were amplified by a biomedical amplifier (MT11, NEC Medical, Tokyo, Japan), and recorded using a data recorder (PC216 Ax, Sony Precision Technology, Tokyo, Japan).

EGG electrodes were pasted by using 2 disposable ECG electrodes (Vitrode Bs, Nihon Kohden, Tokyo, Japan) as shown in Fig. 1. Pasting was performed after confirming sufficient reduction of skin resistance by using Skin Pure (Nihon Kohden).

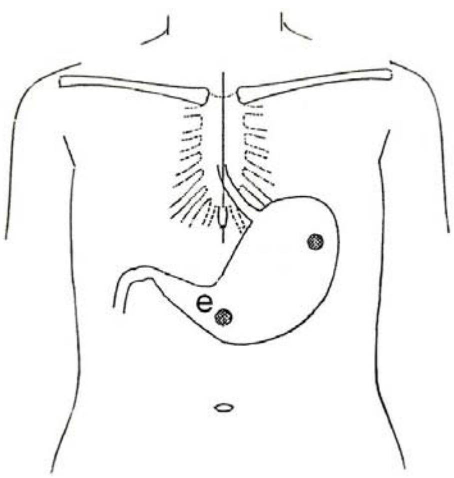

Fig. 1. Pasting position of EGG electrodes.

2.3. Design

Several methods have been proposed for EGG measurement [5], and the number of electrodes and pasting position vary in each method. All these methods involve measurement in the area closest to the stomach pacemaker; therefore, measurement in this area was also performed in the present study.

EGG was recorded in the supine position for 90 minutes, and later, in the sitting position for 30 minutes. Measurement was performed in a sound-insulated (40 dB) experimental room without windows. The room temperature was between 20–24°C, humidity was 40–55%, and the air current was below 0.1 m/s. The chair had a seating surface of 55 cm in width and 55 cm in length, a back of 55 cm in width and 58 cm in length, and the angle between the seating surface and the back was 100 degrees. Subjects were told to finish their meals 2 hours beforehand so that measurements were not affected by the presence of food. Measurement was started between 14:00 and 15:00 for all subjects to avoid the influence of the circadian rhythm (circadian change).

2.3. Procedure

The recorded EGG was A/D converted at 1 kHz to obtain time-series data. A low-pass filter for a 0.15 Hz treble cutoff frequency was applied to the data obtained to remove electronic noise from the incorporated EMG and electronic devices, and resampling was performed at 1 Hz to remove noise.

The EGG time series with noise removed was moved at a 300-point (5-minute) interval in a 1,200-second (20 minutes) time window to divide the data. Following the procedure below, calculation of time series data $\{x_i\}$ and differenced time series $\{x_{i+1} - x_i\}$ can be performed.

1) The minimum delay in which an autocorrelation function is less than 1/e (assumed 0) is defined as embedding delay τ. Then, time series data is recorded again using embedding delay τ as the sampling time. The same numerical value of the embedding delay τ is employed for the time series, using time subtraction to compare smoothness with the trajectory of an attractor reconstructed from the original time series data.
2) An attractor is reconstructed from the time series. The attractor is constructed by embedding the time series data proposed by Takens in phase space. Embedding is a method that draws an trajectory on phase space, supposing a vector whose elements are the values when the time elapses from t to τ, 2τ, …, (N-1)τ as a point in N dimensional phase space (embedding space). N is referred to as the embedding dimension (N = 1, 2, …, 10). Now, the linear correlation between adjacent factors of the vector $\vec{x}_t$ is eliminated by sampling the time series with respect to each embedding delay defined in 1), and distinction of nonlinearity and nonregularity found in the dynamics becomes easier.
3) Regarding $\vec{x}_t$, the methodology that quantitatively assesses the deterministics in time development of an attractor trajectory while calculating directional variation of vector subtraction is the Wayland

Algorithm [15]. In this study, we calculated the translation error from time series data and differenced time series in N dimensional phase space. It is a feature of the Double-Wayland Algorithm [19].

4) Differenced time series produced in the stochastic process often reconstitute an indifferentiable trajectory in the embedding space. This indicates that a translation error derived from the differenced time series exceeds the translation error estimated from time series data. On that basis, we weighed translation error estimated from time series data against that error estimated from time subtraction of time series in N dimensional phase space.

5) If a time series is produced from a chaos process, translation vectors point in almost the same direction unless time implementation τ is too large, because deterministic aspects remain in time development. The minimum translation error would be estimated in such an embedding space that has no false intersection along the trajectory and best reflects the degree of freedom. In this way, the optimum embedding dimension to capture the chaos process can be obtained.

3. Results

EGGs of healthy young (a) and healthy elderly (b) males, recorded over 5 minutes, 10 minutes after initiation of measurement, are shown in Fig. 2. Normal fluctuation cycles are observed in EGGs of Fig. 2. However, the EGGs of healthy young individuals (Fig. 2(a)) showed a large amplitude and unstable fluctuation cycle. In contrast, EGGs of the healthy elderly (Fig. 2(b)) showed a regular pattern.

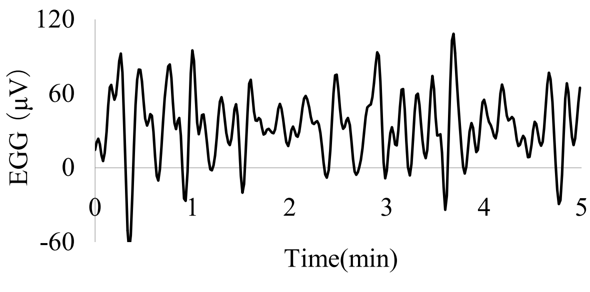

Fig. 2(a). Example of an EGG in a healthy young individual

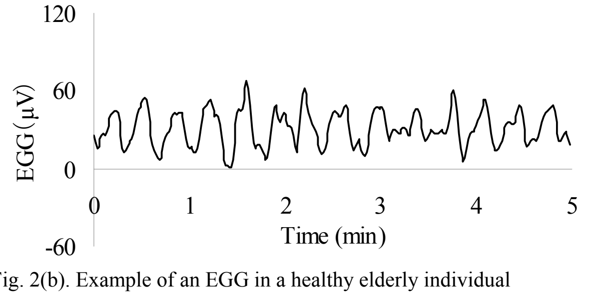

Fig. 2(b). Example of an EGG in a healthy elderly individual

Figs. 3(a–c) show the two-dimensional attractors (τ = 3) formed, based on EGGs of healthy young (Fig. 2(a)) and the healthy elderly (Fig. 2(b))

Fluctuation of the mean average and the standard deviation of the translation errors were estimated from EGGs of the healthy young and healthy elderly individuals in ten-dimensional embedding space (Fig. 4). Translation errors of EGGs in the healthy young ranged from 0.48–0.57, with an average of 0.54 and standard deviation of 0.11. Translation errors of differenced EGGs in the healthy young ranged from 0.40–0.48, with an average of 0.45 and standard deviation of 0.11. Translation errors of EGGs in the healthy elderly ranged from 0.38–0.44, with an average of 0.41 and standard deviation of 0.050. Translation errors of differenced EGGs in the healthy elderly ranged from 0.34–0.38, with an average of 0.36 and standard deviation of 0.043.

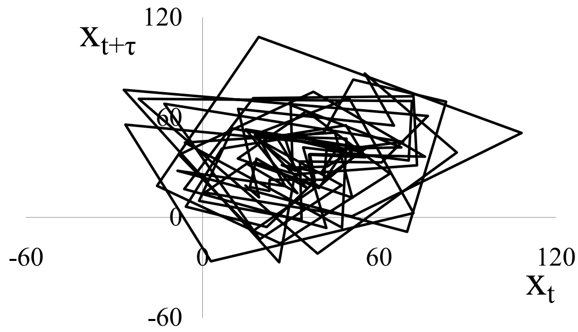

Fig. 3(a). Attractor of a healthy young EGG (Fig. 2(a))

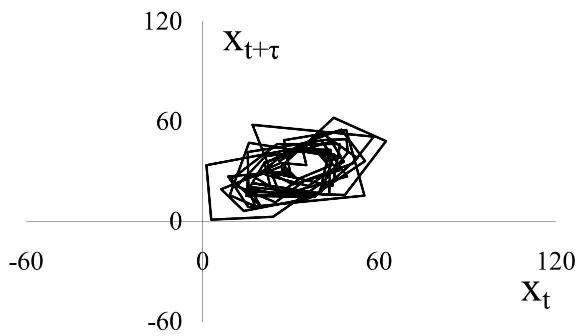

Fig.3(b). Attractor of a healthy elderly EGG (Fig. 2(b))

4. Discussion

In the healthy young, the translation errors of differenced EGGs were significantly less than those of EGGs according to time ($p < 0.05$). The regularity and periodicity of EGGs was considered the cause for this. As shown in Fig. 4, there was also a significant difference in translation errors estimated from EGGs of the healthy young and healthy elderly 20 minutes after the postural change ($p < 0.05$). The results suggest that EGGs of healthy young individuals are more irregular in wavelength and complex in the attractor compared to those of the healthy elderly.

Maximum Lyapunov exponents (MLEs) were estimated based on EGGs of healthy young and healthy elderly individuals [14]. These results also suggest that EGGs of healthy young individuals are more irregular in wavelength and complex in the attractor trajectory compared to those of the healthy elderly, although MLEs of EGGs of the healthy young and healthy elderly generally continued to be flat. EGGs could be described by stationary processes.

Stochastic differential equations have been proposed as mathematical models of the EGG [18]. Numerical solutions involved in stochastic resonance are highly correlated with periodic function, which represents the intestinal EA (6 cpm). The gastric EA in a healthy person might synchronize with the intestinal activity; therefore, synchronization between stomach and intestinal EAs might deteriorate with advancing age.

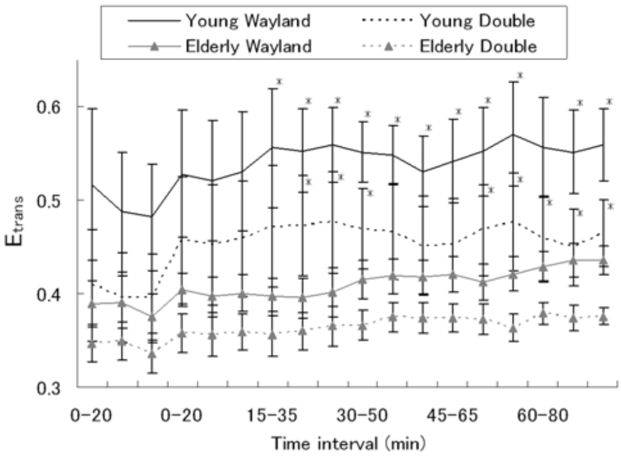

Fig. 4. Average and standard error of translation errors.

References

[1] W. C. Alvarez, "The electrogastrogram and what it shows," *Journal of the American Medical Association,* vol.78, pp.1116-1119, 1922.

[2] S. Homma, "Isopower mapping of the electrogastrogram (EGG)," *Journal of the Autonomic Nervous System*, vol.62, pp.163-166, 1997.

[3] L. K. Kenneth, M. Robert, Handbook of Electrogastrography, Oxford University Press, Oxford, 2004.

[4] J. Z. Chen, R. W. McCallum, Electrogastrography Principles and Applications, Raven Press, New York, 1994.

[5] J. Z. Chen, R. W. McCallum, "Clinical applications of electrogastrography", *American Journal of Gastroenterology*, vol.88, no.9, pp.1324-1336, 1993.

[6] M. Nagai, M. Wada, Y. Kobayashi, S. Togawa, "Effects of lumbar skin warming on gastric motility and blood pressure in humans", *Japanese Journal of Physiology,* vol.53, no.1, pp.45-51, 2003.

[7] A. M. Lyapunov, The general problem of the stability of motion, Comm. Soc. Math., Kharkow, 1892 (in Russian) (reprinted in English, A. M. Lyapunov, "The general problem of the stability of motion," *International Journal of Control*, vol.55, no.3, pp.531-534, 1992)

[8] C. Sato, Theory of nonlinear oscillation. Asakura Shoten, Tokyo, 1970.

[9] M. Tanaka-Yamawaki, M. Tabuse, "A Dynamical Model of the Economic System : Simulation and its Time Series Analysis," *Technical report of IEICE*, NLP98-4, pp.23-29, 1998.

[10] E. Hojin, Y. Shiraishi, N. Furuse, "A Comparison among Lyapunov Exponents Calculation Methods in Human Voice Analysis," *Technical report of IEICE*, CAS2003-3, pp.13-18, 2003.

[11] T. Suzuki, M. Nakagawa, "Fluctuation of the vocal sound and its chaotic and fractal analyses," *Technical report of IEICE*, NLP2004-55, pp.7-12, 2004.

[12] T. Sugiura, T. Iokibe, S. Murata, M. Koyama, "A Method for Discrimination of Arrhythmia by Chaotic Approach," *Journal of Japan Society for Fuzzy*, vol.8, no. 3, pp.541-546, 1996.

[13] Y. Fujiwara, H. Genno, K. Matsumoto, R. Suzuki, K. Fukushima, "Estimating Human Sensations Using Chaos Analysis of Nose Skin Temperature," *Journal of Japan Society for Fuzzy*, vol.8, no.1, pp.95-104, 1996.

[14] Matsuura, Y., Takada, H., "Analysis of the electrogastrograms of gastrectomized subjects by using the maximum Lyapunov exponent," *Technical report of IEICE*, NLP2010-105, pp.29-33, 2010.

[15] Wayland, R., et al. "Recognizing determinism in a time series," *Phys. Rev. Lett*., vol.70, pp.530-582, 1993.

[16] Kothapalli B, "Electrogastrogram simulation using a three- dimensional model," *Med Biol Eng Comput*, vol.31, no. 5, pp.482-486,1993.

[17] Irimia A, Bradshaw LA., "Ellipsoidal electrogastrographic forward modeling," *Phys Med Biol*, vol.50, no.18, pp.4429-4444, 2005.

[18] Matsuura, Y., Takada, H., Yokoyama K., Shimada K., "Proposal for a New Diagram to Evaluate the Form of the Attractor Reconstructed from Electrogastrography," *Forma*, vol.23, no.1, pp.25-30, 2008.

[19] Takada, H., Morimoto, T., Tsunashima, H., Yamazaki, T., Hoshina, H., Miyao, M., "Applications of Double-Wayland Algorithm to Detect Anomalous Signals," *Forma*, vol.21, no.2, pp.159-167, 2006.