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Nonlinear Analysis of Electrogastrograms During Acute Exercise Loads

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Abstract

A percutaneous electrogastrogram (EGG) is a simple and low-restraint way to measure the electrical activity of the gastrointestinal tract. An electrogastrogram examination is a noninvasive method of evaluating gastrointestinal motility and autonomic nervous system activity. However, EGGs are not as widely used in clinical settings as electrocardiograms (ECGs) or electroencephalographs (EEGs) because an EGG can be impacted by electrical activity from the myocardium and the diaphragm (due to respiration), and there is no method to relate the functions of the stomach to the data obtained. This paper examines the effect of exercise on gastric electrical activity using two exercise intensities to confirm the basic biological response of an EGG. It was found that, after high-intensity exercising, the spectrum density at the normal frequency band of the stomach (2.4-3.7 cpm) decreased, which may indicate a decline in gastric activity taking place during exercise. Moreover, after high-intensity exercise, translation error increased significantly. Exercise intensity is thought to affect the electrical activity of not only the gastrointestinal tract, but also of other organs.

Keywords: Electrogastrogram; Autonomic nervous system activity; Exercise intensity; Nonlinear analysis

Introduction

The intestines, which are referred to as "*the second brain*," are part of the digestive tract, and are linked to the brain through the autonomous nervous system and intercellular messages, such as hormones and cytokine [1]. Abdominal pain, diarrhea, constipation and other digestive issues caused by stress are a result of disrupted balance of the autonomic nerves. The intestines not only digest food, but also immunize the body and are linked to cancer and diabetes [2]. In addition, a part of the intestines produces a precursor of serotonin, which not only maintains a person's overall physical health, but also helps stabilize the heart [3]. Therefore, maintaining healthy intestines contributes to mental and physical health. Recently, intestinal floral boom has attracted interest in the fields of intestinal environment and health. In the intestines, probiotic bacteria, pathogenic bacteria, and opportunistic bacteria coexist and protect the intestinal environment. To regulate the intestinal environment, people must eat carefully, exercise, and rest. Exercise promotes circulation and keeps the autonomous nervous system healthy, maintaining the autonomous nerves in this way can encouraging peristaltic movement of the intestines [4,5]. Excessive exercise, however, results in sympathetic nerve dominance, which suppresses digestive tract functions. Therefore, it is important to use appropriate exercise intensity.

The percutaneous electrogastrogram (EGG), which can perform noninvasive, low-restraint measurements of the electric activity that controls gastrointestinal motility, is one way to examine the motor functions of gastrointestinal disorders [6,7]. Regular electrical activity, such as that of the heart, is also seen in the stomach and intestines, where it repeatedly depolarizes and repolarizes. The pacemaker of gastric electrical activity exists in the upper one-third section of the abdomen, where it transmits waves of electrical activity to the pyloric region at a rate of 3 cycles per minute (cpm). This pacemaker is controlled by parasympathetic nervous system activity, but the cyclic electrical activity occurs spontaneously, and is stimulated by a network of islands called "*interstitial cells of Cajal*" (ICCs) [8-11]. Peristaltic movement does not occur when electrical activity is emitted from ICCs. However, when the contraction threshold is exceeded at depolarization, an action potential is produced, which causes peristaltic movement. This electrical activity is divided into two parts: electrical response activity (ERA), which is accompanied by peristaltic movement, and electrical control activity (ECA), which are not [12]. Because an EGG cannot distinguish these, it cannot directly measure peristaltic movement [13]. However, it is thought that EGGs are linked to gastric electrical activity [14], and that it is possible to discover abnormal peristaltic movement using a response confirmation test. This study examines the impact of exercise intensity on gastric electrical activity by a participant undergoing an EGG during exercising.

Materials and Methods

Experimental method

The experiment participants were 19 young men aged from 22-27 (average ± standard deviation: 22.8 ± 1.4) years who had no history of digestive disorders or symptoms. The experiment was fully explained to the subjects prior to the experiment, and they agreed to participate after reading a document describing the purpose and significance of the study and policies outlining protection of privacy, handling of data, and guarantee of interruption. The electronic data obtained during the experiment was recorded under conditions of untraceable anonymity,

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and approval for the experiment (H2017002) was granted by the ethics committee of the Graduate School of Engineering, University of Fukui.

EGGs and electrocardiograms (ECGs) were performed between 60 min of rest in a supine position before and after exercise. The participants ran at a velocity of 10 km/h (high-intensity exercise) and walked at 5 km/h (intermediate-intensity exercise) for 15 min each, on a treadmill (DK-822E, DAIKOU). A control experiment was conducted by having the participants stand still for 15 min (low-intensity exercise). The MET scores of the exercises were approximately 9-10, 3-4, and 1.0-1.5 (which is within the range of everyday exercise) for high-intensity exercise, intermediate-intensity exercise [15], and low-intensity exercise, respectively. Each measurement was taken on a different day, and on each day, the patient sequence was randomized to reduce the effect of ordering.

The EGGs were obtained using an ECG disposal electrode (Blue Sensor, Mets Inc.) as shown in Figure 1.

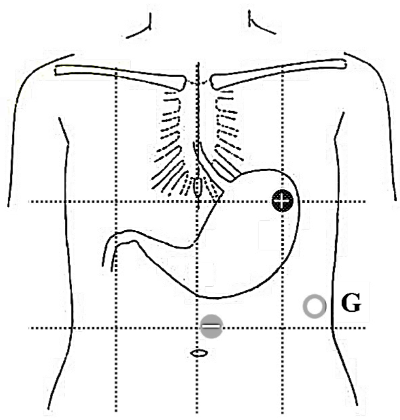

Figure 1: Electrode position.

The electrode was attached to the skin after ethanol was used to disinfect and lower skin resistance. The EGG was recorded using bipolar leads, amplification was performed using a biological amplifier (Biotop mini, East Medic Co., Ltd.), and data was recorded on a PC with an analog input card ([ADA16-32/2(CB)F], CONTEC). The following settings were used for the biological amplifier: sensitivity=100 μV, low frequency cut-off filter=0.02 Hz, and high-frequency cut-off filter=0.5 Hz. Participants were asked to eat 400 kcal of portable food (Calorie-Mate, Otsuka Pharmaceutical Co., Ltd.) two hours before the start of the experiment, but nothing afterwards, to equalize the time food had remained in the stomachs of all the subjects.

Analytical method

The EGGs and ECGs that were recorded were A/D converted at 1 kHz to obtain time series data. A bandpass filter with cut-off frequencies from 0.015-0.15 Hz was applied to the time series data that had been obtained to remove mixed electromyograms (EMGs) and electrical noise due to the EGG time series equipment. The 1 kHz EGG time series was resampled at 10 Hz because the normal cycle of an EGG is relatively slow (about 3 cpm). In this study, the time series was analyzed using running spectrum analysis. The EGG time series were moved and the 8,192-point time windows (roughly 13 min) were divided into intervals of 3000 points (5 min) before each was analyzed. The analyzed sections were recorded (as explained below) with the start times representing the analyzed sections.

Frequency analysis was carried out by performing a Fourier conversion on each time series section, focusing on bradygastria (1.1-2.4 cpm), reference frequency band (2.4-3.7 cpm), and tachygastria (3.7-5.0 cpm), and the power spectral density (PSD) in these frequency bands was calculated [16]. PSD was also calculated using 6.0-8.0 cpm because a study showed that a fluctuation of approximately 7 cpm in an EGG reflects electrical activity of the colon [17].

The EGG time series sections were also analyzed using a statistically-estimated translational error based on a Wayland algorithm [18,19]. Here, the translational error (E_{trans}) estimated based on the Wayland algorithm is an index that quantitively evaluates the smoothness of the course of the attractor buried in the phase space. If the trajectory of the attractor reconstituted in the embedded space is smooth, it is said that the time series is deterministic. If the translational error is a positive, near-zero value, and the model that constitutes the time series is deterministic and large, the error can be viewed as probabilistic. When an object can be modelled using Brownian movement, the translational error value is estimated to be 1.

The ECG measured alongside the EGG was analyzed using heart rate variability (HRV) analysis [20]. HRV can quantify the indices of the sympathetic and parasympathetic nervous systems by analyzing the RR interval (heart rate) from the time and frequency domains. The RR interval time series was abstracted, moved, and divided into 512 time windows at 5 min intervals, which were analyzed so that they corresponded to the sections of the EGG time series. This study assumed the low frequency/high frequency (LF/HF) ratio and heart rate (HR) to be the activity indices of the sympathetic nerves; that the PSD of the LF constituent is from 0.04-0.15 Hz, and that PSD of the HF constituent is 0.15-0.4 Hz.

For the calculated analysis indices, the average values recorded for each time before exercise and for each time after exercise were compared using the Wilcoxon signed-rank test (this study used a significance level of 0.05).

Results

Figure 2 shows the EGG waves corresponding to 10-20 min after the start of measurement for each exercise. The EGG waves after low-intensity exercise show a large period of approximately 3 cpm. In the EGG wave after high-intensity exercise, the amplitude decreased from that of the pre-exercise level, and its period of approximately 3 cpm also reduced in scale.

High-speed Fourier conversions of the EGG time series sections were completed to calculate PSD for each band-bradygastria (1.1-2.4 cpm), reference frequency (2.4-3.7 cpm), tachygastria (3.7-5.0 cpm), and that for the colon (6.0-8.0 cpm); the results are shown in Figures 3-5.

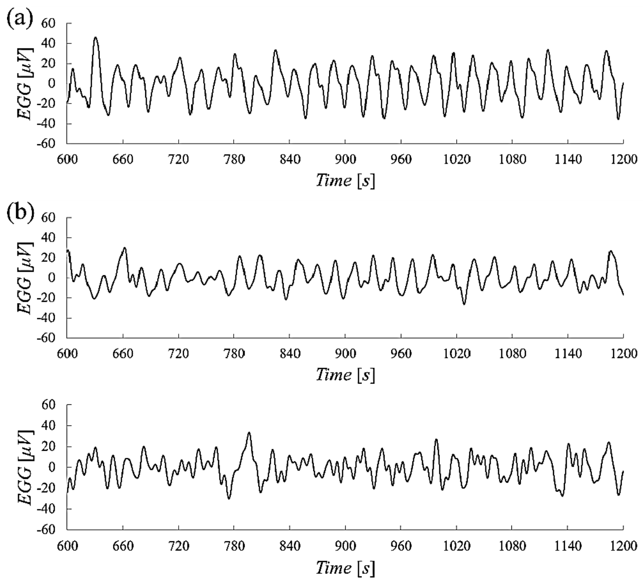

Figure 2: Typical examples of EGGs for a subject, after low-intensity exercise (a), after intermediate- intensity exercise (b), and after high-intensity exercise (c).

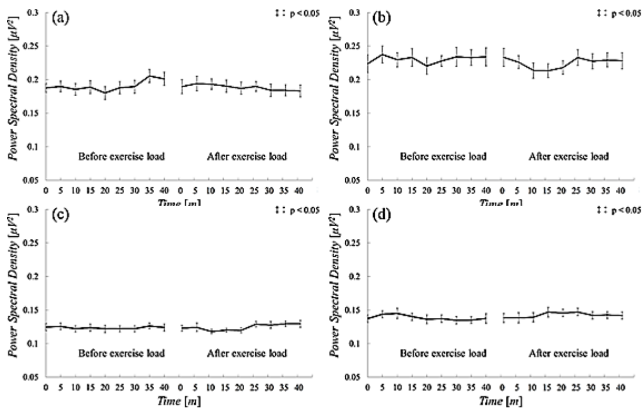

Figure 3: Average PSD (mean ± SE) at low-intensity exercise, for 1.1-2.4 cpm (a), for 2.4-3.7 cpm (b), for 3.7-5.0 cpm (c), and for 6.0-8.0 cpm (d).

For low- and intermediate- intensity exercise, consistent significant differences were not seen in any bands. For high-intensity exercise, the values in the reference frequency band were significantly lower after exercise than they were before (Figure 5). This trend was sustained for 35 min from the start of post-exercise measurements, and the values in the bradygastria band were significantly higher after the performed exercise than before exercise (Figure 5). This significant trend was sustained from 35-45 min.

Next, E_{trans} estimates were calculated using the Wayland algorithm for the time series sections. The results are shown in Figure 6.

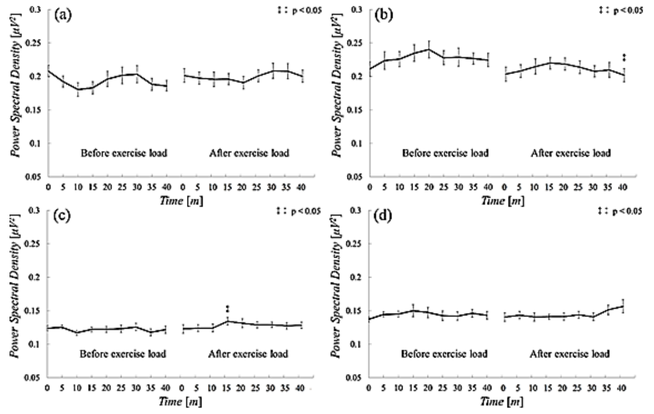

Figure 4: Average PSD (mean ± SE) at intermediate-intensity exercise, for 1.1-2.4 cpm (a), for 2.4-3.7 cpm (b), for 3.7-5.0 cpm (c), and for 6.0-8.0 cpm (d).

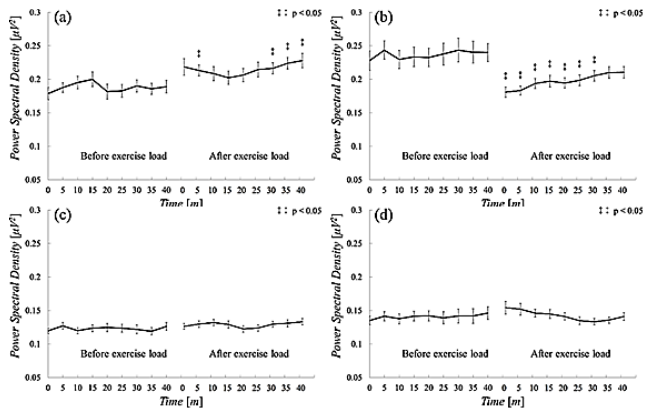

Figure 5: Average PSD (mean ± SE) at high-intensity exercise, for 1.1-2.4 cpm (a), for 2.4-3.7 cpm (b), for 3.7-5.0 cpm (c), and for 6.0-8.0 cpm (d).

The value of E_{trans} remained close to 0.5 in all sections. For low- and intermediate- intensity exercise, no consistent significant differences were seen in any of the bands. For high-intensity exercise, the values were significantly higher after exercise than before ($p<0.05$). This trend was sustained from 15-45 min (Figure 6).

The ECG recorded alongside the EGG was analyzed. For low-intensity exercise, heart rate increased significantly from pre-exercise (at 0 min) to 10 min post-exercise (Figure 7). For intermediate-intensity exercise, heart rate increased significantly from pre-exercise to 30 min post-exercise (Figure 7). LF/HF for intermediate-intensity exercise increased significantly in some cases from pre-exercise to 45 min post-exercise (Figure 8). HF for intermediate-intensity exercise decreased significantly from pre-exercise to 45 min post-exercise (Figure 9). For high-intensity exercise, the heart rate increased significantly from pre-exercise to 45 min post-exercise (Figure 7). LF/HF for high intensity exercise increased significantly from pre-exercise to 45 min post-exercise (Figure 8). HF for high intensity exercise decreased significantly from pre-exercise to 45 min post-exercise (Figure 9).

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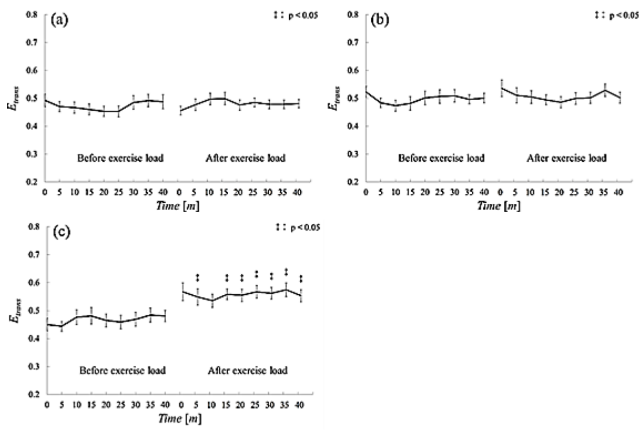

Figure 6: Average value (mean ± SE) of nonlinear analysis, *Etrans* at low-intensity exercise (a), *Etrans* at intermediate-intensity exercise (b), and *Etrans* at high-intensity exercise (c).

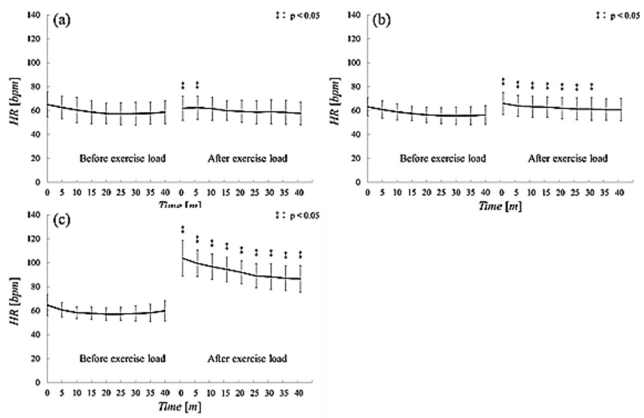

Figure 7: Average value (mean ± SD) of HRV analysis, HR at low-intensity exercise (a), HR at intermediate-intensity exercise (b), and HR at high-intensity exercise (c).

Discussion

In this study, EGGs were used to measure gastric electrical activity during exercising to study the influence of exercise intensity on gastric electrical activity. The results showed that for high intensity exercise, PSD in the gastric normal frequency band tends to decrease, presumably indicating a temporary decline of gastric activity caused by the exercise. This reveals the possibility that digestive activity decreases after high-intensity exercise. For low- and intermediate-intensity exercise, no consistent significant differences were seen in any bands.

For this reason, for exercise with a MET score from 1.0-4.0, the influences of the EGGs on each frequency band were small, and it was confirmed that the gastric electrical activity was constant at this time. For high-intensity exercise (running), the PSD of the gastric normal frequency band decreased (Figure 5). This could indicate a temporary decline of gastrointestinal activity caused by exercise. For high-intensity exercise, a remarkable rise in PSD was seen in the bradygastria band after exercis e (F igur e 5). Bradygastria shows the integration power of the slow wave domain of the power spectrum; thus, it is possible that it caused the delay and reduction of gastric emptying ability after running.

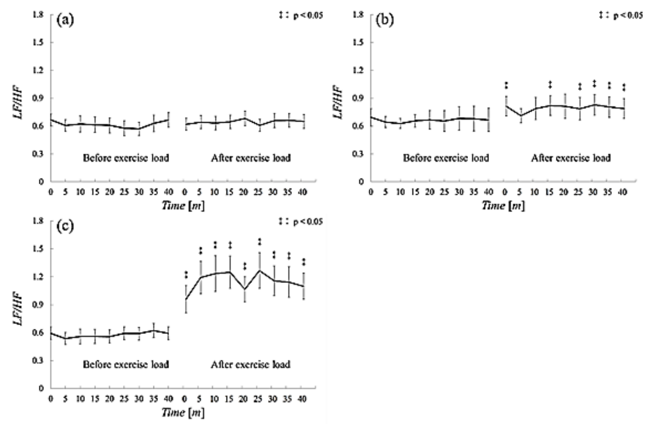

Figure 8: Average value (mean ± SE) of HRV analysis, LF/HF at low-intensity exercise (a), LF/HF at intermediate-intensity exercise (b), and LF/HF at high-intensity exercise (c).

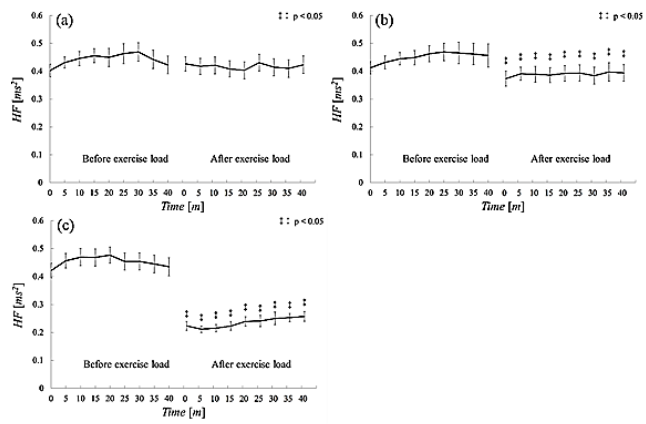

Figure 9: Average value (mean ± SE) of HRV analysis, HF at low-intensity exercise (a), HF at intermediate-intensity exercise (b), and HF at high-intensity exercise (c).

Generally, under the effects of the autonomic nerve balance, parasympathetic nerve activity is temporarily dominant and the digestive tract activity is aggravated, and if sympathetic nerve activity is dominant, the digestive tract activity is repressed. The phenomena shown by this study are presumed to be the results of exercise activity making the sympathetic nerve activity dominant and repressing the digestive tract activity. Clarifying to what extent this temporary parasympathetic nerve activity and repression of digestive tract activity continue, and how they affect later digestive tract activity would be extremely significant from the perspective of hygiene. It is assumed, on the other hand, that a social-intensive environment, an irregular lifestyle that ignores circadian rhythm, a change of environment, excessive stress, and other such conditions disrupt the autonomic nerve balance, thereby causing autonomic imbalance. This is known to cause functional gastrointestinal disorders. In this study, high-intensity exercise is considered to stimulate the regulation ability of the autonomic nerve balance.

E_{trans}, which is a nonlinear analysis index, was used to analyze EGG time series. This confirmed that the value of E_{trans} fluctuates at approximately 0.5 in all time histories, and that the EGG time history is located on the boundary between deterministic and probabilistic theories. This 0.5 threshold is half of the translation error resulting from a random walk. EGG time series has previously been described by stochastic processes [21]. Also, a mathematical model of the EGGs during supine position has been proposed the following SDEs in which the periodic function is added to the Van der Pol equation system as follows.

$$\dot{x} = y - \alpha\, grad\, f(x) + s(t) + \mu w_1(t)$$

$$\dot{y} = -x + \mu w_2(t)$$

$$f(x) = \frac{1}{12}x^4 - \frac{1}{2}x^2$$

Note: The function $s(t) = sin(wt)$ and the white noise $w_i(t)$ represents intestial movements and other bio signal, e.g. myentertic oscillation potentials that are weak and random, respectively (i=1,2). In this paper, for high-intensity exercise, the value significantly increased from pre-exercise until post-exercise.The activity of running could cause variations in the numerical model that describes gastric electrical activity.

Conclusion

This paper reports the use of EGGs to measure gastric electrical activity during exercise to study the influence of the intensity of exercise on gastric electrical activity. The results show that it is possible for high-intensity exercise to be followed by the temporary inducement of a state unsuitable for food digestion. In the future, following multi-faceted discussions of the complexity of generators of EGGs, we will study the use of wearable devices to measure gastrointestinal electrical activity to prepare life logs.

Acknowledgement

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