Abstract: The purpose of this study was to investigate whether nausea or gastric dysrhythmia, including tachygastria, which was determined by electrogastrography (EGG), were observed during optokinetic motion sickness in healthy Japanese volunteers. Twelve volunteers (9 men and 3 women) participated in the study. The subjects were asked to sit in a chair with their heads positioned in the center of a drum whose inside had been painted with black and white stripes. After a 15 min resting period, the drum was rotated at a speed of 60 degree/sec for 15 min. The EGG was continuously recorded for a total of 45 min (15 min resting period, 15 min rotation period, and 15 min recovery period). The severity of nausea was evaluated with a visual analogue scale (VAS) before, immediately after, and 15 min after the cessation of drum rotation. Other motion sickness symptoms were evaluated by scores of subjective symptoms of motion sickness (SSMS). Of 12 subjects who completed the study, 10 complained of nausea immediately after cessation of drum rotation. The VAS score for nausea immediately after the drum rotation period and 15 min after cessation of the rotation was significantly higher than during the resting period. The EGG during the drum rotation period showed a decrease in normogastria, which was accompanied with an increase in tachygastria. We conclude that gastric tachyarrhythmia and nausea may be induced by viewing an optokinetic rotating drum in healthy Japanese subjects who may have a hypersusceptibility to vection-induced motion sickness. The gastric dysrhythmia obtained with EGG could be a useful observation to support the appearance of nausea induced by optokinetic motion sickness.

Key words: motion sickness, electrogastrogram, tachygastria, nausea, visual analogue scale.

MATERIALS AND METHODS

Subjects. Twelve healthy Japanese volunteers (9 men and 3 women, mean [SD] age 27 [3]) participated in this study. No subjects reported gastrointestinal disorders or central nervous system problems, and none had taken any medication for at least 2 weeks before the study. This study was conducted after receiving written consent from the subjects following a full explanation of trial details. The Ethics Committee of the Meiji University of Oriental Medicine approved this study.

EGG recording and data analysis. Percutaneous EGG was applied to record gastric myoelectrical activity. Be-
fore the placement of electrodes, the abdominal skin of recording sites was cleaned with sandy skin-prep jelly (NIHON KODEN, Japan). Disposable Ag-AgCl, electrodes (Vitrode M, NIHON KODEN) were affixed to the abdominal wall. EGG recordings were performed with a portable EGG recorder (EGS2, Nipro Co., Japan) with low and high cutoff frequencies of 1 and 12 cpm. After completion of the recording, EGG data were digitized at a sampling rate of 1 Hz and transferred to a personal computer, then analyzed with a commercially available software program (EGS2, Version 1.31, Gram Corp., Tokyo, Japan). Using a fast Fourier transform (FFT), we computed an algorithm of a power spectra of every 256 s. Each EGG recording was divided into blocks of 60 s without overlapping. On the power spectrum of each 60 s, the dominant frequencies of EGG were defined under 9 cpm. The percentages of the normogastria range (2–4 cpm), the bradygastria range (0–2 cpm), and the tachygastria range (4–9 cpm) were calculated, respectively. The percentage of gastric dysrhythmia was defined as the percentage of time during which normogastria of 2–4 cpm slow waves were absent over the entire observation period.

Circular vection apparatus. A rotating optokinetic drum was used to elicit motion sickness. The testing was carried out using a circular vection drum that was designed according to a report by Stern et al. [7]. The size of the drum was 91.5 cm in height and 76.0 cm in diameter, and the interior was covered with alternating black (3.8 cm wide) and white (6.2 cm wide) vertical stripes. The drum was designed to rotate either clockwise or counterclockwise about its vertical axis at various speeds, resulting in illusory self-motion. At the beginning of the experiment, the subjects were seated inside the stationary drum with their heads positioned in the center of the drum and aligned with the vertical axis. The light source was 30 W incandescent bulbs, which were at the top of the drum’s center. A CCD camera on the top of the drum was connected to a visual display to ensure that the subject’s eyes were open and looking straight ahead at the rotating drum.

Evaluation of the nausea and other symptoms of motion sickness. The subjective magnitude of nausea was evaluated with a visual analogue scale (VAS) before, immediately after, and 15 min after the drum rotation. Operationally, the VAS is a horizontal line, 100 mm long, anchored by a word descriptor at each end with the left hand indicating “no nausea” and the right hand indicating “very severe nausea.” The subjects marked the point they felt represented their current state. The VAS score was determined by measuring the distance in millimeters from the left-hand end of the line to the point the subject had marked.

The subjective symptoms of motion sickness (SSMS), which were translated into Japanese by the authors, were obtained prior to and during the drum rotation period. The SSMS score, which is based on the questionnaire developed by Graybiel et al. [9], depends on the occurrence and magnitude of symptoms of nausea, dizziness, headaches, drowsiness, warmth, sweating, increasing salivation, decreasing salivation, and stomach discomfort.

Procedures. All subjects were asked to fast for at least for 4 h before the experiment. After placement of the EGG electrodes, the subjects were asked to sit and relax on the chair for a total of 45 min: 15 min baseline period, 15 min drum rotation, and 15 min recovery period. EGG was continuously recorded before, during, and after the drum rotation. After the 15 min baseline, the drum was rotated around the subject at a speed of 60 degree/sec. The subject was told to look straight ahead at the black and white stripes in the optokinetic drum. To quantify the severity of nausea induced by the drum rotation, the visual analogue scale (VAS) was recorded before, immediately after, and 15 min after the cessation of drum rotation.

Statistical analysis. A one-way ANOVA followed by Dunnet’s multiple comparison test was applied to compare the VAS and the EGG data before, during, and after the drum rotation. Statistical significance was determined with P less than 0.05. Dunnet’s test was performed to identify the pairs of significance when the F test was significant by one-way ANOVA. Data were expressed as means ± SD.

RESULTS

Nausea and other symptoms

Of 12 subjects, 10 reported nausea immediately after cessation of the drum rotation. The other subjective symptoms mentioned by these subjects included dizziness (n = 10), drowsiness (n = 8), warmth (n = 6), headaches (n = 6), sweating (n = 4), increasing salivation (n = 4), decreasing salivation (n = 1), and stomach discomfort (n = 8) (Table 1). In two subjects who did not complain of nausea, one complained of drowsiness and warmth and another reported no subjective symptoms. No subjects asked that the drum rotation be stopped during rotation. The severity of nausea induced by the rotation in the 10 subjects evaluated with VAS is shown in Fig. 1. To be expected, the VAS score before the drum rotation period was zero. Immediately after the cessation of rotation, the mean VAS score

| Table 1. Frequency of symptoms reported for the subjective symptoms of motion sickness (SSMS) during drum rotation in subjects with/without nausea. |
|-----------------|-----------------|-----------------|
| Nausea (+) N = 10 | Nausea (-) N = 2 |
| Dizziness | 10 | 0 |
| Drowsiness | 8 | 1 |
| Warmth | 6 | 1 |
| Headaches | 6 | 0 |
| Sweating | 4 | 0 |
| Increasing salivation | 4 | 0 |
| Decreasing salivation | 1 | 0 |
| Stomach discomfort | 8 | 0 |
was increased to 67.6 (SD, 18.5), and 15 min after cessation it was 45.2 (SD, 12.7). The increase in these scores from baseline showed a statistical significance ($P < 0.01$, one-way ANOVA and Dunnet’s test) (Fig. 1).

**Changes in the EGG**

Figure 2 shows the changes in the normogastria, tachygastria, and bradygastria in the 10 subjects who reported nausea and developed gastric arrhythmia. Before the drum rotation, these subjects reported no symptoms, and a high component of normogastria in EGG was observed. However, in the drum rotation period, the percentage of normogastria decreased rapidly in contrast to the apparent increase in tachygastria. By the end of the recovery period, normogastria of EGG was reestablished gradually. There were significant differences in the mean percentage of normogastria (Fig. 3a) and tachygastria (Fig. 3b) both during ($P < 0.01$ for both normogastria and tachygastria) and after the drum rotation period ($P < 0.01$ for normogastria and $P < 0.05$ for tachygastria), when compared with those before the drum rotation period.

Although the proportion of bradygastria showed no significant changes during the drum rotation period, it was increased after cessation of the rotation. There was a significant difference in the mean percentage of bradygastria between the before and after periods ($P < 0.01$) (Fig. 3c).

In the remaining two subjects who did not complain of nausea during the drum rotation period, normogastria was observed throughout the entire experimental period.

**DISCUSSION**

Percutaneous electrogastrography (EGG), which can detect electrical variations in the stomach through the surface of the abdominal skin, has been investigated for clinical application [1, 3, 4, 10, 11]. In 1922, Alvarez [12] recorded a 3 cycle/min (cpm) sinusoidal wave using electrodes placed on the abdominal skin. Since then, there have been several studies concerning EGG, and it is considered that gastric electrical potentials break out from a “pacemaker” located on the upper gastric body along the greater curvature [13, 14], which consists of interstitial cells of Cajal (ICC) [15]. These potentials are related to an electrical pacing function and the power of gastric con-
traction [3, 16–18] that is regulated by autonomic nerves [19]. This phenomenon is abolished after total gastrectomy [10, 20].

Gastric electrical dysrhythmia of the EGG is believed to be associated with gastric symptom such as nausea and dysmotility [1–5]. Numerous studies have indicated that gastric dysrhythmia is detected during nausea [1–3, 5–8]. It is not only found in several clinical circumstances, but is also induced by chemical agents such as epinephrine [21]; glucagons [22]; metenkephalin, or PGE₂ [23]; atropine sulfate; neostigmine [11, 24, 25]; morphine; histamine [25]; insulin; secretin; CCK-pancreozymin; pentagastrin [26]; and serotonin (5-HT₃) [27]. However, nausea is not necessarily caused by administering these chemical agents. Although gastric dysrhythmia of EGG appears when nausea exists, it does not always accompany nausea.

Indeed, it has been shown that the symptom of motion sickness is increased by the administration of naloxone [28]. Koch et al. [29] have shown that subjects who subsequently develop symptoms of motion sickness when exposed to a rotating optokinetic drum have a significantly higher level of peripheral beta-endorphins than subjects who experienced no symptoms. It was suggested that central endorphins might play a role in inhibiting the development of optokinetic motion sickness. Furthermore, an increase in plasma vasopressin associated with nausea and vomiting in some species (but not all) has been demonstrated [30–32]. In humans, the vasopressin level in plasma was increased during motion stimuli such as optokinetic motion sickness [30]. It is considered that the vasopressinergic neuroendocrine system may be stimulated in healthy subjects who experience nausea and develop gastric dysrhythmia during vection-induced motion sickness.

Fig. 3. Comparison of the mean percentage of normogastria, tachygastria, and bradygastria before and after the drum rotation. The Y-axis of each figure indicates the percentage of normogastria, tachygastria, and bradygastria of EGG, respectively. There were significant differences in the mean percent of normogastria (a) and tachygastria (b), before and during the drum rotation period and before and during the recovery period, respectively. Also, there was a significant difference in the mean percent of bradygastria before and during the recovery period (c). If a significant difference was obtained by one-way ANOVA, the pairs of the differences were identified using Dunnet’s test. The data are presented as mean ± SD. Asterisks indicate statistical significance at *P < 0.05 and **P < 0.01. N.S. indicates non-significance.

It has been shown that vection provoked significant nausea in Chinese subjects when compared with African-American and Caucasian subjects [33–35]. Research on vection in Japanese subjects has not been published. In our results, 10 out of 12 Japanese subjects complained of nausea immediately after cessation of the drum rotation, of which the percentage (83%) was comparable to those reported in the Chinese subjects. Therefore we speculate that Asian subjects may have a hypersusceptibility to vection-induced motion sickness compared to African-American and/or Caucasian subjects, which is consistent with Stern’s hypothesis [33–35].

Studies of vection-induced motion sickness reflect important brain-gut and gut-brain interactions [5]. The vection-induced motion sickness is increased by the administration of naloxone. Koch et al. have shown that subjects who subsequently develop symptoms of motion sickness when exposed to a rotating optokinetic drum have a significantly higher level of peripheral beta-endorphins than subjects who experienced no symptoms. It was suggested that central endorphins might play a role in inhibiting the development of optokinetic motion sickness. Furthermore, an increase in plasma vasopressin associated with nausea and vomiting in some species (but not all) has been demonstrated. In humans, the vasopressin level in plasma was increased during motion stimuli such as optokinetic motion sickness. It is considered that the vasopressinergic neuroendocrine system may be stimulated in healthy subjects who experience nausea and develop gastric dysrhythmia during vection-induced motion sickness.

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tion stimulus is a purely visual stimulation. During drum rotation, neurosensory afferent information from the vestibular and proprioceptive systems indicates no movement of the individual. Thus in susceptible subjects, the rotating drum induces a neurosensory mismatch that results in the symptoms of nausea and tachygastria and increased beta-endorphin [29], vasopressin [30, 32], and epinephrine [33]. However, neurohumoral mechanisms that mediate vection-induced tachygastria are still not well understood. It was considered that the vection-induced motion sickness with the optokinetic drum is a non-invasive neurological stimulus that be used safely for the investigation of the mechanisms of nausea accompanied with gastric dysrhythmia in human subjects.

From the results of the present study, we conclude that the gastric tachyarrhythmia and nausea were induced by viewing an optokinetic rotating drum in healthy Japanese subjects, and these subjects may have a hypersusceptibility to vection-induced motion sickness. The gastric dysrhythmia obtained with EGG could be a useful observation to support the appearance of nausea induced by optokinetic motion sickness.

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