Adverse Effects of Whole-Body Vibration on Gastric Motility

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Summary: To investigate the response of gastric motility to whole-body vibration (WBV) exposure, electrogastrography (EGG) and gastric manometry were performed in 10 healthy male volunteers. Sinusoidal vertical vibration of three different frequencies (4Hz, 8Hz, and 16Hz) with a constant vibration magnitude of 1.0 ms\(^{-2}\) (rms.) was randomly given to the subject seated on the platform of a vibrator for 10 min. Exposure to vibration of 4 and 8 Hz decreased the amplitude of EGG wave and of the power spectrum corresponding to a slow wave component at fasting state. Food intake (solid meal 80 g, 135 cm\(^3\), 400 kcal) enhanced gastric motility showing about 2.5-fold in the power spectrum, of which response modes during and after vibration exposure were similar to those at fasting state. The periodical manometric change around one cpm was observed during vibration exposure under the condition of food intake. Short-term exposure to WBV led to a suppression of the activity of gastric smooth muscles and affect contraction wave. These responses may result from resonance of vibration frequency as a mechanical factor and stomach contents, and increase regulation of neurohumoral factors due to vibration stress.

Key words whole-body vibration (WBV), gastric motility, electrogastrography, manometry, food intake

INTRODUCTION

According to several epidemiological studies, long-term exposure to whole-body vibration (WBV) produces gastrointestinal disorders [1,2]. It is therefore of interest to ask whether exposure to WBV is one of the risk factors for gastric disorders such as gastric neurosis and non-ulcerative dyspepsia (NUD), associated with abnormality of gastric motility. Experimental studies of the effect of acute exposure to WBV on gastric motility in healthy subjects have produced inconsistent findings. Kjellberg and Wikström [3] reported a transient increase of gastric motility during exposure to WBV. On the other hand, a suppressive effect on gastric motility of acute exposure to WBV was found in our previous experiment [4]. This discrepancy may depend on differences in the experimental conditions, for example differences of vibration frequency and amplitude, as well as differences in stomach content.

Fluoroscopy, ultrasonography, scintigraphic gastric emptying, gastric manometry, and electrogastrography (EGG) have been employed for evaluating gastric motility under physiological and pathological conditions [5]. Above all, EGG and gastric manometry are usually used as conventional methods for measuring gastric motion [6-9]. The cutaneous EGG can show the electric activity of gastric smooth muscle picked up by electrodes on the skin. Physiologically, gastric electric activity consists of the pacemaker potential (electric control activity: ECA) and the spike potentials (electric response activity: ERA) [10]. Changes of the power spectral density of the EGG, especially of the slow wave component, may reflect the contractile activity of the stomach [11,12]. Gastric manometry can provide data suggestive of myopathy, neuropathy, or obstructive disorders. Simultaneous use of EGG and gastric manometry may provide valuable information on gastric motility.

In our previous experiments, brief exposure to WBV of 10 Hz suppressed gastric motility [4]. The
suppressive effect may have resulted from neurohumoral factors [13]. The aim of this study was to investigate the role of vibration frequency and food intake, in the changes of gastric motility in response to WBV and to clarify the mechanism of these effects.

MATERIALS AND METHODS

Subjects

Ten male healthy volunteers without any gastrointestinal complaint participated in this study. The mean age was 22.4 years (range 21-26 years). Prior to the study, the procedures of the experiments were carefully explained to all the subjects, and the informed written consent form was signed by each of them.

Experimental protocol

To eliminate the effects of biorhythms and meals on the EGG, each study was commenced at about 5:00 pm. All subjects were asked to eat and drink nothing after a regular lunch. The mean fasting time was 4.5 hrs. Firstly, the subjects were asked to sit on a hard flat seat without backrest in a comfortable posture. Sinusoidal vibrations of three different frequencies (4 Hz, 8 Hz and 16 Hz) with an acceleration magnitude of 1.0 ms\(^{-2}\) (rms) were randomly given to the subject for 10 min. The vibration stimulus was produced by an electromagnetic shaker (ASE-385, AKASHI, Japan). The subjects were divided into two groups: One group was exposed to vibration with the frequencies in the sequence of 4, 8 and 16 Hz, the other was treated with the frequencies in the reverse sequence. The EGGs were recorded before, during and after vibration exposure. Secondly, to investigate the effect of food intake on gastric motility, each subject was tested in the fasting state and with the stomach filled with a regular solid meal (80 g, 135 cm\(^3\), 400 kcal).

After gentle abrasion of the skin in order to enhance its electrical conductivity, two disposable Ag/AgCl electrodes (Vitrode, Nihon Kohden, Japan), 6 cm apart horizontally, were placed at the midpoint between the xiphoid and the umbilicus. A reference electrode was affixed to the right upper quadrant of the abdomen. The EGG signals were amplified with a pre-amplifier (AB621-G, Nihon Kohden, Japan). The time constant was 5 s. The high-frequency cutoff was set at 0.2 Hz to minimize interference from non gastric signals. The EGG signals were simultaneously digitized at 4 Hz by an analog-to-digital converter and filtered to remove noise of frequency greater than 9 cycles/min (cpm) and less than 0.9 cpm.

To examine the relationship between electric muscle activity and intraluminal pressure on gastric motility, EGG and gastric manometry were simultaneously measured in two subjects. For the recording of gastric manometry, gastric intraluminal pressure was converted to an electric potential by an electric transducer system on a catheter (Micro Digitrapper, SYNECTICS MEDICAL, Sweden). After overnight fasting, a trans-nasal catheter including three micro transducers was carefully inserted into the stomach with the subject in the supine position. The catheter diameter was 0.4 cm, and the transducers were located at 2, 7 and 12 cm from the catheter distal end. The sensors were positioned in the antrum under X-ray fluoroscopy. Changes of gastric pressure were measured continuously during the experiments in the sitting posture. These pressure signals were automatically digitized at 4 Hz of sampling rate and directly stored on a Micro Digitrapper. To clarify neurohumoral effects on gastric motility, some drugs were used: an anti-cholinergic agent (scopolamine, 10 mg), alpha- and beta-adrenergic blocking agents (prazosin, 1 mg and 20 mg of propranolol). Each drug was given to the patient orally one hour before the experiment.

The noise level induced by the electromagnetic shaker during the experiments was 70 to 72 dB(A). The ambient temperature was maintained at 23-25 °C.

Data analysis

The frequency analysis of the EGG was done by fast Fourier transform (FFT). The power spectrum was calculated every 10 min at different recording periods. Two EGG parameters were evaluated [14]: (1) the mean dominant frequency of the EGG, indicating the peak frequency in the power spectrum, (2) the relative power (%) of the slow wave component (2-5 cpm) and of the tachygastria component (5-9 cpm), which was calculated by dividing the area under each of these components by the total area under the power spectrum in the frequency range 0.9 to 9.0 cpm, and by multiplying the quotient by 100. Figure 1 shows a representative EGG wave form (A) and its power spectrum (B). Regular and rhythmic EGG waves were associated with a two-peaked power spectrum. The main component was a peak at around 3 cpm, which was called the slow wave component (2-5 cpm). The smaller component, with
Fig. 1. A representative electrogastrogram (EGG) (A) and its power spectrum with two major components (B).

Fig. 2. A typical case of gastric manometric waves. In the fasting state, a sequence of phases 1 to 3 repeats about every 3 hours (A). Food intake produces irregular contractions continuing for 3 to 4 hours (B).
peak in the frequency range of 5 to 9 cpm, was named tachygastria.

The gastric manometrogram was evaluated for changes in wave form pattern [5]. Figure 2 shows a representative case of gastric manometrogram in the fasting state (A) and after food intake (B). In the fasting state, gastric manometric waves were divided into 3 phases: Phase 1 was a ‘silent phase’ with very small contraction waves. Random irregular contraction waves were observed in Phase 2. Phase 3 was defined by rhythmical, large contraction waves. A sequence of these 3 phases appeared repeatedly about every 2 hours in normal subjects [15]. In the food intake state, the contraction waves were irregular.

Statistics

Data are expressed as medians (25%, 75%) because of the lack of normality in the distribution. The data of different recording periods for vibration exposure in the same subjects were statistically compared using the Wilcoxon signed-rank test. Differences were considered to be significant at p<0.05.

RESULTS

Different effects in vibration frequencies

Table 1 shows the change of EGG during and after WBV at three different frequencies. The mean dominant frequency of EGG was 3.3 cpm before vibration (4 Hz) exposure, composed of 70.0% of slow wave and 17.5% of tachygastria. All subjects showed a dominant frequency between 2 and 5 cpm at each vibration frequency. No significant differences of the mean dominant frequency and the relative powers were shown before vibration exposure among the three different frequencies. The dominant frequency and the relative power of the slow wave component of the spectrum decreased during vibration exposure of different frequencies, but the changes were not statistically significant. In contrast, the total power of the EGG decreased significantly during vibration at 4 and 8 Hz. No obvious changes in EGG and its power spectrum were observed during 16 Hz vibration.

Modulation of EGG wave and its power spectrum by food intake

Figure 3 shows the EGG wave forms and their power spectra before, during and after exposure to WBV (4 Hz) in the food intake state. Food intake enhanced gastric motility, as shown by a marked increase in the amplitude of the EGG waves and of the slow wave component of the power spectrum. As in the fasting state, vibration decreased the amplitude of the EGG waves and of its slow wave component of the power spectrum. After stopping vibration exposure, the amplitudes of the EGG waves and of

<p>| TABLE 1. |
| EGG changes induced by three different vibration frequencies in the fasting state |</p>
<table>
<thead>
<tr>
<th>4Hz</th>
<th>8Hz</th>
<th>16Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>During</td>
</tr>
<tr>
<td>Dominant Frequency (cpm)</td>
<td>3.3 (2.8, 3.3)</td>
<td>2.8 (2.6, 3.0)</td>
</tr>
<tr>
<td>Relative power (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow wave</td>
<td>70.0 (60.2, 73.9)</td>
<td>64.8 (55.9, 73.5)</td>
</tr>
<tr>
<td>Tachygastria</td>
<td>17.5 (12.6, 24.6)</td>
<td>25.0 (17.2, 32.8)</td>
</tr>
<tr>
<td>Total power (%)</td>
<td>100.0 (65.0, 97.0)</td>
<td>93.0 (60.0, 140.5)</td>
</tr>
</tbody>
</table>

The values are median (25%, 75%). n=10 *p<0.05 by Wilcoxon signed rank test.
Relative power indicates the proportion of total power comprised by each component. Total power is calculated as a percentage of the previous condition.
WHOLE-BODY VIBRATION AND GASTRIC MOTILITY

Fig. 3. Influence of food intake on electrogastrograms (EGG) and their power spectra under the condition of exposure to whole-body vibration (4Hz).

Fig. 4. Simultaneous recordings of EGG and manometry before, during and after exposure to vibration (4Hz) in the fasting state.

**TABLE 2.**

*EGG changes induced by whole-body vibration (4Hz) before and after food intake*

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Control</th>
<th>Food intake</th>
<th>During vibration</th>
<th>After vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Frequency (cpm)</td>
<td>3.3 (2.8, 3.3)</td>
<td>–</td>
<td>2.8 (2.6, 3.0)</td>
<td>2.8 (2.8, 3.3)</td>
</tr>
<tr>
<td>Fasting state</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative power (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow wave</td>
<td>70.0 (60.2, 73.9)</td>
<td>–</td>
<td>64.8 (55.9, 73.5)</td>
<td>71.8 (62.5, 72.9)</td>
</tr>
<tr>
<td>Tachygastria</td>
<td>17.5 (12.6, 24.6)</td>
<td>–</td>
<td>25.0 (17.2, 32.7)</td>
<td>16.2 (13.1, 21.0)</td>
</tr>
<tr>
<td>Total power (%)</td>
<td>100.0</td>
<td>–</td>
<td>80.5 (65.0, 97.0)</td>
<td>104.1 (60.0, 140.5)</td>
</tr>
<tr>
<td>Dominant Frequency (cpm)</td>
<td>2.8 (2.8, 3.3)</td>
<td>3.3 (2.8, 3.3)</td>
<td>2.8 (2.8, 3.3)</td>
<td>3.3 (3.3, 3.3)</td>
</tr>
<tr>
<td>Food intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative power (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow wave</td>
<td>73.2 (64.0, 78.7)</td>
<td>–</td>
<td>85.1 (70.8, 86.9)</td>
<td>79.5 (70.5, 84.8)</td>
</tr>
<tr>
<td>Tachygastria</td>
<td>19.0 (15.1, 27.1)</td>
<td>–</td>
<td>10.3 (5.8, 18.0)</td>
<td>15.0 (8.2, 20.0)</td>
</tr>
<tr>
<td>Total power (%)</td>
<td>100.0</td>
<td>–</td>
<td>255.6 (130.5, 363.0)</td>
<td>–</td>
</tr>
</tbody>
</table>

The values show median (25%, 75%). n=10 *p<0.05 by Wilcoxon signed rank test.
the slow wave component of its power spectrum recovered gradually. Table 2 shows the effect of WBV on EGG in the fasting state and in presence of food intake. During and after vibration exposure, qualitatively similar responses were observed in both fasting and food intake states. However, the magnitude of the responses in the food intake state was larger than in the fasting state. In both conditions, the relative powers (%) of the controls were almost the same. Food intake produced a significant increase in the relative power of the slow wave component, and also led to a significant decrease of the tachygastria component. The total power of EGG was also increased about 2.5 times as median. During vibration exposure, the relative power of the tachygastria in the fasting state was significantly larger than that in the food intake condition (p<0.05). On the contrary, the relative power of the slow wave in the fasting state was significantly smaller than that in the food intake condition (p<0.05).

**Relationship between EGG and gastric manometry**

Figures 4 and 5 show typical simultaneous EGG and gastric manometric recordings in the fasting and food intake states, respectively. In the fasting state, a typical gastric manometric change as shown in phase 3 (Fig. 2) was observed before, during and after vibration exposure. A remarkable manometric change by vibration was not observed in spite of a decrease in the amplitude of EGG and its power spectrum. On
the contrary, food intake produced a slightly reduced amplitude of EGG and a marked decrease in the irregular contraction of manometric waves as shown in Fig. 5. In particular, periodic changes at 1 cpm were observed during vibration exposure, which disappeared when the vibration exposure was ceased.

**Influence of some drugs**

We observed the influence of some drugs on the EGG and its power spectra. Drugs used were the anticholinergic agent scopolamine (10 mg), the alpha-adrenergic blocking agent prazosin (1 mg) and the beta-adrenergic blocking agent propranolol (20 mg). All drugs were given orally. Scopolamine and prazosin produced a decrease in the amplitude of EGG and its power spectra (Fig. 6). Under the influence of vibration exposure, these responses were much reduced. However, propranolol increased the amplitude of EGG despite the lack of effect on the power spectra.

**DISCUSSION**

Short-term exposure to WBV (4 and 8 Hz for 10 min) depressed the slow wave component of the power spectrum of the EGG. In contrast, exposure to 16 Hz vibration did not produce changes in the amplitude of the EGG and its power spectrum. These findings suggest that a short-term WBV exposure suppresses gastric motility, because a relative decrease of power spectral density in the slow wave component reflects a decrease in the contractile activity of the stomach [11,12]. We had previously shown that another WBV frequency with short-term exposure (10 Hz) for 5 min reduced the power density of the slow wave component [4]. In the evaluation of the human response to WBV, the resonance frequency of body parts should be considered because the biodynamic transmission of vibration depends on this factor. In particular, knowledge of the resonance frequency of the human body to WBV is of utmost importance for evaluating the physiological reaction. The movement of human internal organs increases at vibration frequency of 3-5 Hz and 7-10 Hz of around the resonance frequency [16]. Our findings seem consistent with these considerations. The gastric movement by vibration exposure may be maximum at 4 or 8 Hz as compared to the movement at 16 Hz.

Food intake is a very important factor influencing gastric motility. An increase in the amplitude of EGG after food intake has been observed by some investigators [17,18]. It is widely recognized that the increase of the contractile activity due to eating has a good correlation with the amplitude of the EGG and of the slow wave component [19]. However, the pattern of EGG and the change of power spectrum were similar between fasting and food intake states, although the slow wave component during vibration exposure in the food intake state was larger than in the fasting state. This may be related to the increase of passive movement of the stomach which depends on the stomach contents due to food intake.

The suppressive mechanism by WBV on gastric motility may involve neurohumoral and mechanical factors [10]. It is known that scopolamine can suppress stomach smooth muscle contraction, while prazosin may also suppress the contraction of the pylorus ring; in contrast, propranolol would increase the stomach muscle tone and increase the EGG power spectrum [20]. In other words, one may expect suppression of the amplitude of the EGG and its power spectra by the anti-cholinergic and alpha-adrenergic blocking agents, and increase of these parameters by the beta-adrenergic blocking agent [21]. However, exposure to WBV produced a further reduction in the slow wave component of the EGG after pretreatment with these drugs. The reduction of slow wave component by vibration and by these drugs may be due to not only the autonomic nerves activity but also humoral and mechanical factors. As for the humoral factors, the secretion of gastric juice is stimulated by gastrin and the parasympathetic nerve. Gastrin released from the pyloric glands can enhance gastric motility and stimulate hydrochloric acid secretion. Parasympathetic stimulation increases the secretion of acid, mucus and pepsinogen by the action of acetylcholine. Tactile stimulation of the surface of the gastric mucosa can also influence gastric secretion. Exposure to WBV may cause a mechanical effect on the stomach wall, leading to an increased gastric secretion, while gastric motility is not affected [22]. Finally, another possible mechanism for the suppression of gastric motility during WBV is a direct mechanical influence of vibration.

Food intake can provoke a periodic manometric change, at a frequency of around 1 cpm, by vibration exposure. According to Bortolotti et al. [23], the relationship between EGG wave and manometric change is not constant. In case of normal myoelectric activity in EGG, a burst of spikes was associated with the pressure waves. However, no correspondence was observed under severe myoelectric rhythmic disorders. While the EGG represents the total electric activities of gastric smooth muscles, gastric
manometry reflects total motility of the stomach. Although the mechanism of the periodic and wavy change, at around 1 cpm, is not known, WBV exposure may produce a mechanical effect on gastric motility. In conclusion, acute exposure to WBV may suppress the activity of gastric smooth muscle and contraction. These responses may be influenced by resonance of vibration frequency and stomach contents, which would be regulated by the increased release of neurohumoral substance due to vibration stress.

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REFERENCES