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EVALUATION OF FREQUENCY WEIGHTING (ISO 2631-1) FOR ACUTE EFFECTS OF WHOLE-BODY VIBRATION ON GASTRIC MOTILITY

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The aim of this study was to investigate the effects of exposure to whole-body vibration (WBV) and the ISO 2631/1-1997 frequency weighting on gastric motility. The gastric motility was measured by electrogastrography (EGG) in nine healthy volunteers. Sinusoidal vertical vibration at a frequency of 4, 6·3, 8, 12, 16, 31·5, or 63 Hz was given to the subjects for 10 min. The magnitude of exposure at 4 Hz was 1·0 m/s^2 (r.m.s.). The magnitudes of the other frequencies gave the same frequency-weighted acceleration according to ISO 2631/1-1997. The pattern of the dominant frequency histogram (DFH) was changed to a broad distribution pattern by vibration exposure. Vibration exposure had the effect of significantly reducing the percentage of time for which the dominant component had a normal rhythm and increasing the percentage of time for which there was tachygastria ($p < 0.05$). Vibration exposure generally reduced the mean percentage of time with the dominant frequency in normal rhythm component. There was a significant difference between the condition of no vibration and exposure to 4 and 6·3 Hz of vibration frequency ($p < 0.05$). The frequency weighting curve given in ISO 2631/1-1997 was not adequate for use in evaluating the physiological effects of WBV exposure on gastric motility.

1. INTRODUCTION

The effects of whole-body vibration (WBV) on human health, comfort and perception are dependent on the vibration frequency. In human response to vibration, various frequency weightings have been defined. Different frequency weightings should be considered for evaluating the vibration effect on the human body. The International Standard (ISO) is one of the principal standards currently available. It defines methods for the measurement and evaluation of WBV. It is generally recommended that the frequency weighting method described in ISO 2631/1-1997 [1] is used for evaluating the relationships between vibration frequency and the various human responses. The weighting curve in ISO 2631/1-1997 assumes that the same human response would be expected at different frequencies of vibration exposure if the weighting curve is applied to the exposure level. This frequency weighting has been supported by many biodynamics and physiological studies [1] and it has been used as a guide for the effects of WBV on health, and especially for low-back disorders [2].

Some epidemiological studies have reported an increased prevalence of gastrointestinal symptoms in workers exposed to WBV [3, 4]. It remains to be seen whether exposure to WBV is a specific risk factor for functional disorders associated with abnormalities of gastric motility, such as gastric neurosis and non-ulcerative dyspepsia [5]. Although there

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have been several experimental studies on the effects of acute exposure to WBV on human gastric motility in healthy subjects, the findings have been inconsistent [6, 7]. The actual effects of WBV exposure on gastric motility thus remain unclear. In addition, there are no physiological data relating gastric motility and the frequency response and WBV frequency.

Cutaneous electrogastrography (EGG) is used to measure the electric activity of gastric smooth muscles, and is also a potentially useful and non-invasive technique for evaluating gastric motility [8]. The indices of the frequency components and their power spectra provide reliable information about gastric motility. The human gastric signals are divided into three components: bradygastria (< 2 cpm), normal rhythm (2–4 cpm), and tachygastria (4–9 cpm) [5]. EGG has been widely used as a diagnostic method for functional disorders associated with abnormalities of gastric motility. The purpose of this study was to assess the efficacy of the EGG-based, frequency weighting procedure given in ISO 2631/1-1997 for evaluating the physiological effects of WBV exposure on gastric motility.

2. METHODS

Nine healthy male volunteers (mean age, $20{\cdot}2 \pm 1{\cdot}5$ (SD) years range 18–23 years) (mean body mass index, $22{\cdot}4 \pm 1{\cdot}6$ (SD)) participated in this study. They had no history and no digestive signs and symptoms of any gastrointestinal tract disorders. The subjects were asked not to eat and drink after a regular lunch. The mean fasting time was $4{\cdot}0 \pm 0{\cdot}53$ (SD) h.

Subjects were seated on a platform equipped with a vibrator and exposed to sinusoidal vertical vibration at one of seven randomly chosen frequencies (4, 6·3, 8, 12, 16, 31·5, or 63 Hz) for 10 min with a 2 h interval on 2 different days. Each subject was also monitored under a condition of no vibration for a control. The magnitude of exposure at 4 Hz was $1{\cdot}0\,m/s^2$ (r.m.s.) for 10 min. The magnitudes of the other frequencies gave the same frequency-weighted acceleration described in ISO 2631/1-1997 [1].

After gentle abrasion of the skin to enhance the electrical conduction, two disposable Ag/AgCl electrodes, 6 cm apart horizontally, were placed at the middle level 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. The time constant was 5 s. The high-frequency cut-off 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 high- and low-frequency noises for exclusion of more than 9 cycles/min (cpm) noise and less than 0·9 cpm noise. The EGG was continuously recorded for 10 min before and 10 min after the vibration exposure for a total recording time of 30 min.

Running spectral analysis was performed on the 10 min recordings which were divided into 16 segments using a window of 128 s duration every 32 s, thus resulting in an overlap of 96 s between successive segments. A spectrogram was calculated from every segment using fast Fourier transform (FFT). Dominant frequencies (DF) obtained from each spectrogram were classified as follows: bradygastria component, < 2 cpm; normal rhythm component, 2–4 cpm; and tachygastria component, 4–9 cpm. The dominant frequency was defined as the frequency at which the EGG power spectrogram peaked. The dominant frequency histogram (DFH) of 16 spectrograms was calculated from running spectral analysis because this index can relate to gastric motility [9]. In addition, the percentage of total observation time during which the dominant frequency was in bradygastria, normal rhythm or tachygastria components was determined. This is used as a concept for evaluating the

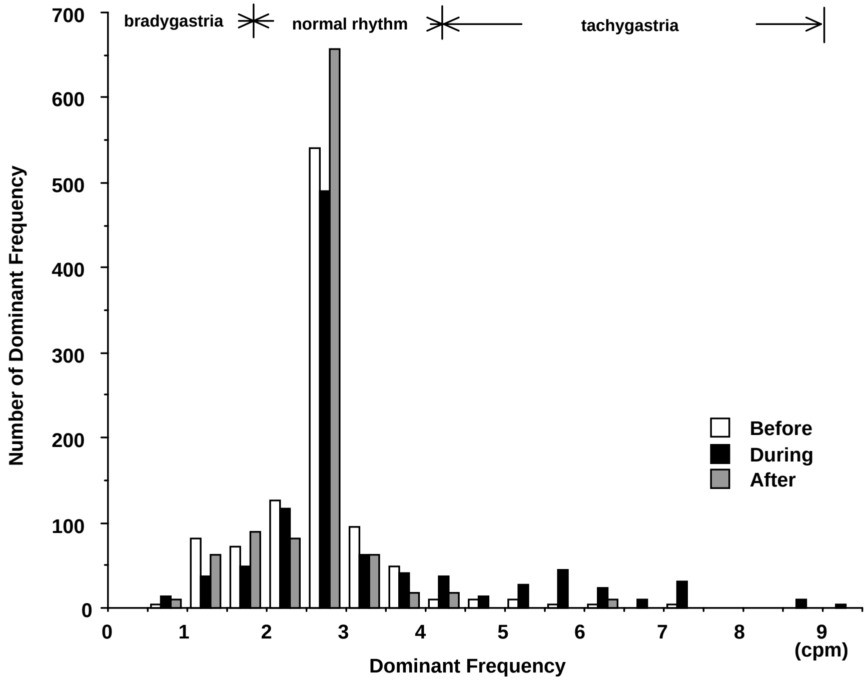

Figure 1. Dominant frequency (DF) histogram of nine subjects before, during and after vibration exposure.

pattern of gastric myoelectrical activity [10]. A paired t-test was used to evaluate the difference between exposure periods (before, during, after) for the percentage of time at the dominant frequency. Multiple comparison with Tukey HSD was applied to judge the statistical significance between vibration frequencies. Differences were considered to be significant at $p < 0{\cdot}05$.

3. RESULTS

Figure 1 shows the dominant frequency histogram (DFH) of nine subjects before, during and after vibration exposure to seven frequencies. Although the DF was most frequently observed at 2·8 cpm in the three conditions, the peak value at 2·8 cpm was reduced by vibration exposure and recovered after exposure. The pattern of DFH changed to a broad distribution, especially an increase of tachygastria component during vibration exposure.

The mean percentage of time ascribed to a normal rhythm component was significantly lower during vibration exposure than before ($p < 0{\cdot}05$) (Figure 2). On the other hand, the mean percentage of time occupied by the tachygastria component was significantly higher during vibration exposure than before it ($p < 0{\cdot}05$).There was no significant change in the index of bradygastria component by vibration exposure.

Figure 3 illustrates the mean percentage of time when the DF was in a normal rhythm and in a tachygastria component in response to seven different vibration frequencies and with no vibration condition as a control. Although exposure to vibration generally reduced this value, the response to vibration frequency was quite different. There was a significant difference in this value between the no-vibration condition and the exposure to vibration frequencies of both 4 and 6·3 Hz ($p < 0{\cdot}05$). No obvious changes were observed at

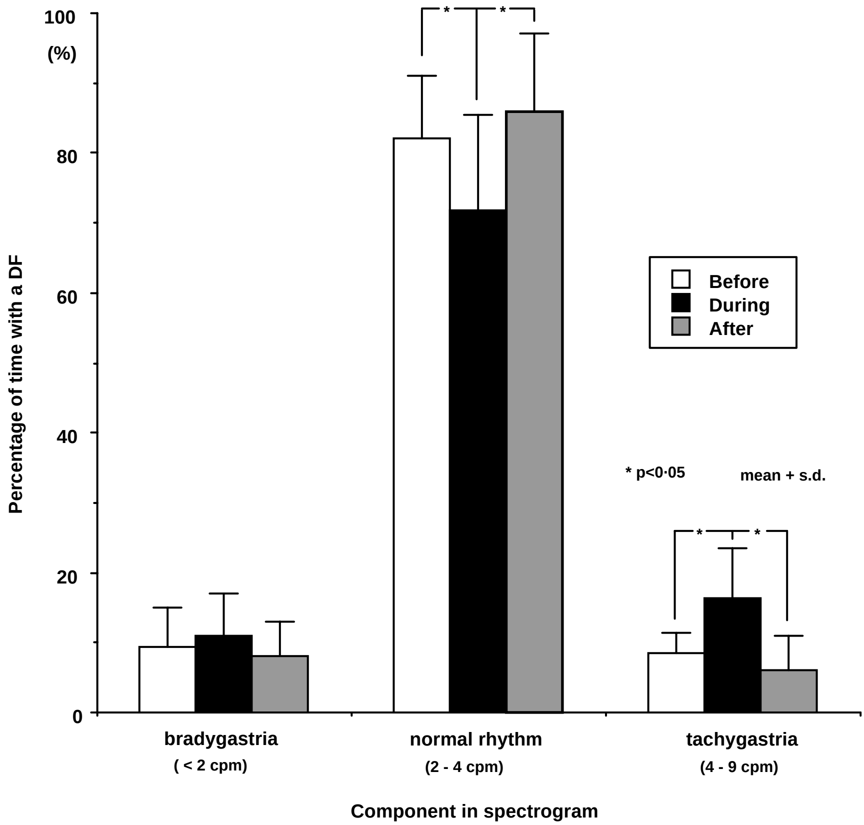

Figure 2. The mean percentage of time with a dominant frequency (DF) in bradygastria (< 2 cpm), normal rhythm (2–4 cpm) and tachygastria (4–9 cpm) components of nine subjects before, during and after vibration exposure.

vibrations of 8, 31·5 and 63 Hz. On the other hand, the mean percentage of time in tachygastria component generally increased with vibration exposure. However, these changes were only significant in the cases of 4 and 6·3 Hz ($p < 0{\cdot}05$).

4. DISCUSSION

The main finding of the present study was that exposure to WBV produced a decrease in the normal rhythm component and an increase in the tachygastria component. This finding suggests that short-term WBV exposure can affect gastric motility rhythm. There is a high percentage of tachygastria components in patients with several disorders [9–11]. However, the effect of short-term WBV exposure may not be so strong because normal subjects have a normal rhythm for more than 70% of the time [12]. There have been reports of a change of magnitude in the power spectrum during WBV exposure [6, 7, 13]. Kjellberg and Wikström [6] observed a biphasic phenomenon which initially increased and then gradually decreased the power spectral density at frequencies of 3 cpm due to 3 Hz WBV. Ishitake *et al.* [7, 13] have also reported that a short-time exposure to WBV can reduce the power spectral density of the normal rhythm component. Although these results imply that gastric contraction can be affected by WBV, there is no further information on gastric

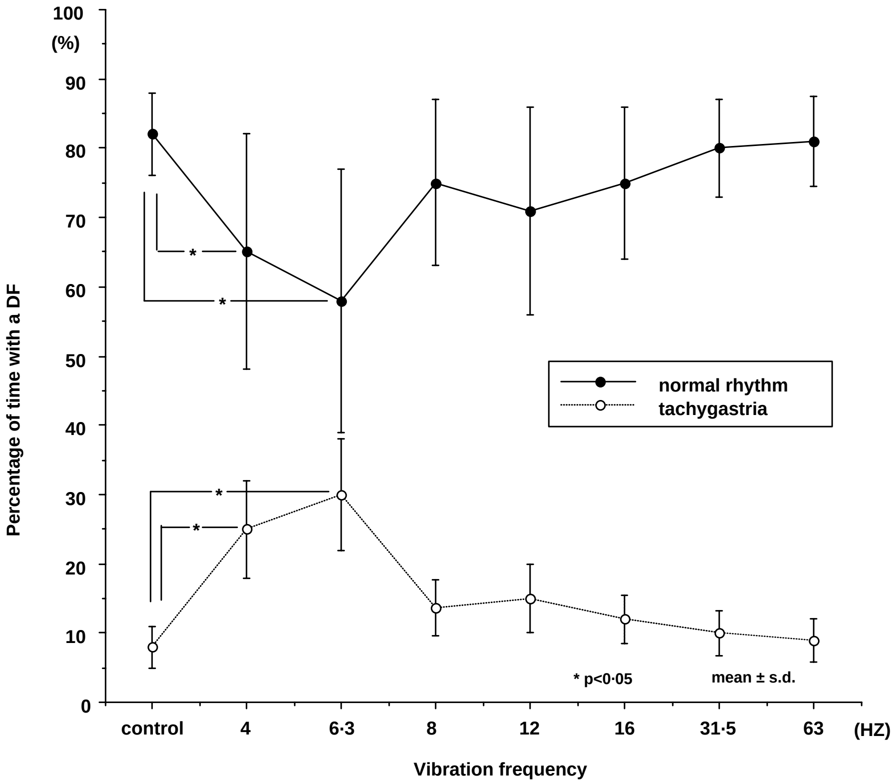

Figure 3. The mean percentage of time with a dominant frequency (DF) in normal rhythm and tachygastria components at different vibration frequencies.

motility. These studies did not take into account the percentage of time at the dominant frequency. The dominant frequency of the EGG can accurately represent the frequency of gastric motility [9].

A statistically significant difference in the response to vibration frequency on gastric motility was not found between 4, 6·3 Hz and other frequencies. The short-term exposure to WBV used in this study suppressed gastric motility in a frequency dependent manner in spite of the application of the ISO 2631/1-1997 frequency weighting procedure. It is suggested that the frequency weighting of ISO 2631/1-1997 may underestimate the effect on gastric motility of exposure to WBV with lower frequencies (4, 6·3 Hz). Although there is no clear explanation for this phenomenon, it may involve the resonance frequency of the human body, since the effects of WBV at this frequency are considered important in physiological and pathological reactions to WBV. Dupuis and Zerlett [14] found that movement of the internal organs of human subjects increased at vibration frequencies of 3–6 Hz. This means that the human internal organs have two main resonance frequencies. They assumed that there was considerable strain in the tissues in this frequency range.

The ISO standard was designed to prevent health effects, particularly those with respect to lower back disorders, associated with long-term exposure to WBV. Although spinal health risk is an important problem among occupations with WBV exposure, there has been no definite evidence of dose–effect relationships between vibration exposure level and injuries [15]. Several frequency weightings have been proposed for different postures and different vibration axes. Different frequency weighting should be considered for specific effects on human health due to WBV. In conclusion, the frequency weighting curve given in

ISO 2631/1-1997 was not adequate to use in evaluating the effects of WBV on gastric motility.

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