Effect of Short-term Exposure to Whole Body Vibration in Humans: Relationship between Wakefulness Level and Vibration Frequencies

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Received 7 October 2008, accepted 19 September 2009

Summary: The purpose of this study was to clarify the influence of different vibration frequencies on wakefulness level. Subjects were 7 healthy male university students aged 21.9 ± 1.6 years (mean). All students were non-smokers. Three exposure conditions were used (10 Hz vibration, 20 Hz vibration, and no vibration). Whole-body vertical vibration was applied to subjects sitting on a car passenger seat using a whole-body vibration shaker (CV-300, Akashi) at a single frequency (10 or 20 Hz) at an acceleration level of 0.3 ms\(^{-2}\) r.m.s. for 24 min. The objective wakefulness level based on EEGs was evaluated in terms of the alpha attenuation coefficient (AAC) obtained by the Alpha Attenuation Test (AAT). As parameters of psychological stress, salivary 3-methoxy-4-hydroxyphenylglycol (MHPG) and homovanillic acid (HVA) were used. The subjective wakefulness level was evaluated using a questionnaire based on the Kwansei Gakuin Sleepiness Scale (KSS), which is a scale developed for the Japanese based on the Stanford Sleepiness Scale (SSS). The KSS score, representing the subjective wakefulness level, decreased after the exposure irrespective of the exposure condition, but the decrease was not significant. The AAC, representing the objective wakefulness level, significantly decreased only after vibration exposure (10 Hz/20 Hz) but did not differ between the two vibration frequencies. No significant changes were observed after exposure to whole-body vibration in MHPG or HVA as parameters of vibration-related stress. The AAC decreased after exposure to whole-body vibration (10 Hz/20 Hz), suggesting a decrease in the wakefulness level. However, no differences were observed in the influence of the two different vibration frequencies test.

Key words acute effect, electroencephalogram, wakefulness level, whole-body vibration

INTRODUCTION

In the context of work environments, whole-body vibration refers to the rhythmic vibratory movements transmitted to the human body through the seats and floor of cars, trucks, railroad cars, or construction machines. Whole-body vibration is considered to affect health due to the synchronization and amplification of the complex vibration frequencies by the body. Long-term exposure to whole-body vibration has been reported to increase the risk of lower back pain in people operating industrial machines [1-4]. On the other hand, suitable vibration can produce a positive effect on the human body. Several studies have suggested an association between whole-body vibration in public transportation and recovery from fatigue after driving or sedative effects on neonates [5,6]. These findings suggest that whole-body vibration influences the autonomic and central nervous system.
Factors determining the influences of vibration on the human body are the amplitude, frequency, direction and duration of exposure to vibration. Concerning the relationship between vibration frequency and the resonance frequencies of different organs in the human body, frequency-dependent effects have been reported in digestive organs (4-5 Hz) and the spinal cord (3-5 Hz) [7]. However, whether vibration frequency characteristics are associated with a decrease in the wakefulness level has not been determined. Previous studies have suggested a decrease in the wakefulness level of train drivers due to fatigue caused by their work environment [8,9], and it is hypothesized that physical stimulation by whole-body vibration affects the activity of the autonomic and central nervous system.

We previously reported [10] a decrease in the wakefulness level due to short-term exposure to whole-body vibration using electroencephalogram (EEG) recordings, but did not evaluate differences in this level using varying frequencies or exposure times. In addition, EEG recordings alone are not a sufficient parameter for evaluating wakefulness level. The psychological stress parameters 3-methoxy-4-hydroxyphenylglycol (MHPG) and homovanillic acid (HVA) reflect the kinetics of central catecholamine activity. Therefore, they can be considered as physiological parameters of the wakefulness level, and may be useful for evaluating the influences of vibratory movements on the central nervous system.

We hypothesized that vibration frequency characteristics affect the wakefulness level in whole-body vibration environments. In this study, the influence of the vibration frequency characteristics of whole-body vibration on the wakefulness level was evaluated by measuring subjective and objective parameters of the wakefulness level, and concentrations of MHPG and HVA in saliva as parameters of vibration-related stress.

### METHODS

#### Subjects

The subjects comprised 7 healthy male university students aged 21.9±1.6 years (mean ± SD). They were 169.2±4.2 cm tall and weighed 66.1±12.1 kg. All students were non-smokers. No differences were observed among the 3 exposure conditions with regard to sleep time on the day before the experiment or the postprandial period before tests on the day of the experiment (Table 1).

#### Methods

The subjects were instructed to spend the 3 days prior to the experiment as usual, avoiding excessive drinking and insufficient sleep. They were also instructed not to consume caffeine-containing foods after lunch on the day of the experiment and to have commercially available solid food (Calorie Mate: 200 kcal) as a light meal at 17:00. All experiments were initiated at 20:00 because of expected intra-day variations in the wakefulness level. All participants were subjected to 3 experimental conditions (whole-body exposure to 10 Hz vibration, 20 Hz vibration, and no vibration) on 3 different days. The order of the 3 conditions was randomly determined to avoid order-related influences. The median (25%-75%) interval between different experiments was 6 days (3.7-16). The experimental schedule is shown in Fig. 1.

Whole-body vertical vibration was applied for 24 min to subjects sitting in the passenger seat of a car using a vibration shaker (ASE-385; AKASHI, Japan). The vibration was applied at a single frequency (10 or 20 Hz) and an acceleration level of 0.3 ms⁻² r.m.s. according to ISO 2631-1-1 [11], based on field measurement data of actual exposure on bulldozers in a work environment. The subjects were instructed not to use the back support during exposure to whole-body vi-

### Table 1.

<table>
<thead>
<tr>
<th>Status of the subjects before the experiments</th>
<th>WBV (–)</th>
<th>WBV (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>21.9±1.6</td>
<td></td>
</tr>
<tr>
<td>BMI (Body Mass Index)</td>
<td>23.1±3.7</td>
<td></td>
</tr>
<tr>
<td>Sleeping time (hour)</td>
<td>7.7±2.0</td>
<td>7.1±0.6</td>
</tr>
<tr>
<td>Time to previous meal (hour)</td>
<td>2.6±0.7</td>
<td>2.4±0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.7±0.8</td>
</tr>
</tbody>
</table>

(Mean±SD)
Vibration acceleration was maintained at a constant level using a vibration level meter (VM-52, RION). EEGs were recorded after the application of electrodes following the international 10-20 method (C3-A2, O1-A2, O2-A1). To reduce electric resistance, cutaneous sebum was adequately removed using a polisher before electrode application. EEGs were continuously recorded during the experimental period. The subjects maintained a relaxed posture on a sofa with a support for the back and armrest before and after exposure to whole-body vibration, while staring at a black dot (3.0 cm in diameter) placed 2.0 m in front of them. After electrode application, the subjects were interviewed regarding sleep time and activities performed during the previous 3-day period prior to the experiment and their physical condition on the day of the experiment.

Salivary MHPG and HVA were used as psychological stress parameters. Saliva was collected by applying a cylindrical cotton swab to the oral cavity for 2 min and using a conical centrifugation tube for saliva collection (Salivette) before and after exposure to whole-body vibration. The collected saliva was returned to the conical tube, centrifuged for 3 min, and stored at −20°C until measurement. After deproteinization of both MHPG and HVA with 25% perchloric acid, the fluorescence of the supernatant obtained after centrifugation was measured by HPLC at an excitation wavelength of 280 nm and a fluorescence wavelength of 320 nm.

The subjective wakefulness level was evaluated using the Kwansei Gakuin Sleepiness Scale (KSS) questionnaire [12]. This is a scale developed for the Japanese based on the Stanford Sleepiness Scale (SSS) devised by Hoddes in 1972, and consists of 22 items. The mean of the scores for 22 items is assumed to be the total score, and a mean score close to 0 indicates a high wakefulness level, while a mean score close to 7 indicates a low wakefulness level.

EEGs were recorded using an electroencephalograph (Neurofax EEG-8314; Nihon Kohden, Tokyo, Japan). By performing FFT (1 section, 4 sec; sampling frequency, 100 Hz) using a biosignal time series analysis program (Trend Viewer, Kissei Comtec, Nagano, Japan), we calculated the power spectra of the θ (4-7 Hz), α (8-11.8 Hz), and β (14-30 Hz) waves. In addition, we obtained the mean values of power spectra when the eyes were open and when they were closed. In this study, the objective wakefulness level based on EEGs was evaluated in terms of the alpha attenuation coefficient (AAC) obtained by the Alpha Attenuation Test (AAT) reported by Michimori et al. [13,14] The power spectrum of α waves increases when the eyes are closed. When the wakefulness level is high, blocking becomes marked when the eyes open, and the power spectrum of α waves markedly decreases. When the wakefulness level is low, there are few differences in the power spectrum of α waves between when the eyes are open and when they are closed. Based on these findings, the AAC is defined as the mean power spectral value of α waves when the eyes are closed/that when they are open. A higher AAC indicates a higher wakefulness level. The AAC was analyzed using EEG signals obtained from O1-A2.

In AAT, experiments with the eyes open and closed were repeated 3 times for 1 min each in the sitting position according to the instructions of the examiner;
these experiments were performed before and after exposure to whole-body vibration. Measurement of the subjective wakefulness level and saliva collection were performed before and after AAT.

The methods used for experiments where no whole-body vibration was applied were similar to those employed for whole-body vibration, except that there was no exposure to vibration itself. The period corresponding to the whole-body vibration exposure time was spent in the sitting position in the shaker, as in the other experiments. The subjects entered the room for experiments at about 20:00. The room temperature, humidity, background noise level, and illumination in the experimental room were maintained at approximately 21.4 ± 0.8 °C, 50 ± 5%, 64 dB (A), and 510 lx, respectively.

Statistical analysis
Since we could not confirm the normality of the distribution of the subjective wakefulness level (KSS), objective wakefulness level (AAC), or salivary MHPG/HVA (Kolmogorov-Smirnov test), Wilcoxon’s signed rank test as a non-parametric method was used for comparison between the presence and absence of whole-body vibration exposure. P < 0.05 was regarded as significant. Statistical analysis was performed using a statistical software package (SPSS 11.5 J).

Ethical considerations
The subjects were provided with oral and written explanations of the purpose/methods/contents of the investigation. They were also informed that they had the right to refuse participation in this investigation, that the results of the investigation would remain confidential and be used only for this study, and that individuals could be identified only by the research representative. Following this, consent was obtained from all subjects. When the subjects inquired about the contents of the measurement, an adequate explanation was provided.

Whole-body vibration exposure was set at a level that did not affect health according to the ISO 2631-1 standard. We explained to the subjects that their participation in this study had no short- or long-term effects on their health, and that experiments would be immediately discontinued in cases such as the discomfort condition of the subjects. This study was approved by the Ethics Committee on Medicine of Kurume University (Study No. 2562).

Definition of terms
Amplitude: The amplitude of a vibration can be quantified by its displacement, its velocity or its acceleration. For practical convenience the acceleration is usually measured with accelerometers.
Frequency: The frequency of vibration, which is expressed in cycles per second, affects the extent to which vibration is transmitted to the body (e.g., to the surface of a seat), the extent to which it is transmitted thought the body (e.g., from the seat to the head), and the effect of the vibration in the body.
Direction: Vibration may take place in three translational directions and three rotational directions. For seated persons, the translational axes are designated x-axis (fore-and-aft), y-axis (lateral) and z-axis (vertical).
Duration: The period of exposure to vibration

RESULTS

Subjective awareness level
KSS: Changes in the wakefulness level in terms of the KSS score are shown in Table 2. The KSS score increased after the experiment irrespective of whole-body vibration exposure, indicating a decrease in the subjective wakefulness level, but no significant difference was observed.

Objective awareness level
EEG (AAC): Changes in AAC as a parameter of the objective wakefulness level are shown in Fig. 2. The

<table>
<thead>
<tr>
<th>KSS</th>
<th>Before</th>
<th>After</th>
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<tr>
<td>10Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBV (–)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>3.6 (3.6-4.3)</td>
<td>4.5 (4.3-4.9)</td>
</tr>
<tr>
<td>20Hz</td>
<td></td>
<td></td>
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<tr>
<td>WBV (+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>3.6</td>
<td>4.6</td>
</tr>
<tr>
<td>20Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>3.1 (2.4-3.5)</td>
<td>4.3 (3.6-4.9)</td>
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<tr>
<td>20Hz</td>
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</table>

Table 2. Changes in subjective wakefulness level as measured by KSS

Kurume Medical Journal Vol. 56, No. 1, 2, 2009
AAC decreased irrespective of the exposure conditions, indicating a decrease in the awareness level, but significant differences were observed only in the presence of exposure to vibration. There was no significant difference between the two frequencies.

**Biochemical examination (MHPG/HVA):** Changes in MHPG and HVA under each whole-body vibration exposure condition are shown in Table 3. The MHPG concentration (median) increased after the exposure experiment in the presence of exposure (10 and 20 Hz). The HVA concentration (median) increased in the absence of exposure and in the presence of exposure (10Hz). There was no significant difference among the three conditions.

**DISCUSSION**

The KSS as a subjective measure of awareness level decreased after the experiment under each exposure condition, but the decreases were not significant. The AAC as an objective measure of awareness level significantly decreased after the experiment only in the presence of exposure (10 and 20 Hz). In addition, no significant change was observed in MHPG or HVA as parameters of psychological stress. Thus, the vibration acceleration level used in this study (0.3 ms\(^{-2}\) r.m.s.) affected the awareness level without causing psychological stress. However, since no difference was observed in the responses between the two vibration frequencies (10 and 20 Hz) used in the present study, no specific vibration frequency characteristics could be identified.

Concerning the influences of exposure to whole-body vibration on the wakefulness level, Landström et al. exposed subjects to a single frequency vibration (3 Hz) or random vibration for 15 min at the same acceleration level (0.3 ms\(^{-2}\)), and analyzed the wakefulness level, focusing on changes in the power spectra of frequency components of EEGs. They observed a significant increase in the θ wave component and a significant decrease in the α wave component after exposure to vibration, indicating a decrease in the awareness level after exposure [15]. Although the frequency employed in their study differed from those used in ours, their results support ours. We previously reported a decrease in the wakefulness level after exposure to 10 Hz whole-body vibration for a short period (12 min) [10]. The level of exposure to whole-body vibration used in our previous study (vibration acceleration, 0.6 ms\(^{-2}\) r.m.s.) was twice the level in this study. Since no psychological stress parameters were measured in our previous study, whether this acceleration level causes psychological stress is unclear. However, even the vibration exposure level used in the present study reduced wakefulness, a result which will be useful when designing future studies to determine the threshold level of vibration exposure needed to reduce the wakefulness level.

**Fig. 2.** Changes in objective wakefulness level by AAC

![Graph](image_url)

**TABLE 3.**

<table>
<thead>
<tr>
<th>Condition</th>
<th>MHPG (median, 25th-75th percentile)</th>
<th>HVA (median, 25th-75th percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WBV (-)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>MHPG</td>
<td>17.3 (7.1-33.2)</td>
<td>17.1 (14.2-34.0)</td>
</tr>
<tr>
<td>HVA</td>
<td>7.4 (3.6-15.2)</td>
<td>10.4 (4.6-14.8)</td>
</tr>
<tr>
<td><strong>WBV (+)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>10Hz</td>
<td></td>
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<tr>
<td>20Hz</td>
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</table>

In train drivers, a decrease in the wakefulness lev-
el due to fatigue has been suggested [8,9]. However, our results suggest that the wakefulness level is affected not only by fatigue but also by certain direct effects of exposure to whole-body vibration. The vibration acceleration level used in this study (0.3 ms\(^{-2}\)) is similar to the general vibration exposure level in work environments involving traveling and operating industrial machines, which suggests that occupational exposure to whole-body vibration can be a risk of a decrease in the awareness level of drivers. Therefore, further detailed evaluation of the relationship between exposure to whole-body vibration and the wakefulness level may be useful for preventing accidents in occupations that involve driving. In the future, it will be necessary to evaluate the influences of whole-body vibration on the human body in terms of the wakefulness level as well as performance, such as changes in the response time and work efficiency under vibration exposure conditions similar to actual driving-based work environments.

The wakefulness level has been reported to be affected not only by vibration exposure but also by exposure to a single noise [16]. In this study, the wakefulness level decreased with time even in the absence of vibration exposure. This may be due to the background noise of 64 dB (A), which could have affected the wakefulness level as a stimulus, reducing the difference in the decrease in the wakefulness level between the presence and absence of exposure to whole-body vibration. The vibration acceleration level in this study was 0.3 ms\(^{-2}\), which is similar to the general vibration exposure level in work environments involving traveling and operating industrial machines. Therefore, it is also possible that this acceleration level induced comfort and relaxation rather than discomfort in the subjects, resulting in a decrease in the wakefulness level. The influences of vibration exposure itself could not be evaluated, probably because of the background noise and the fact that the levels of exposure to whole-body vibration were similar to those experienced in passenger cars in ordinary life. This is supported by the comments of most subjects, who reported that they were comfortable during exposure to whole-body vibration.

AAC, used as an objective parameter of the wakefulness level, is obtained by performing AAT, which was developed by Michimori et al. [13,14]. A correlation has been reported between the AAC and multiple sleep latency test (MSLT) using objective physiological parameters. Unlike MSLT, which requires various experimental conditions, AAC allows estimation of the objective wakefulness level via a simple procedure in a short time, and may therefore be more useful. In this study, we were able to measure AAC in a short period with minimum discomfort; therefore, AAC may be appropriate as a parameter of the wakefulness level during exposure to whole-body vibration. The wakefulness level may be affected by sleep and wakefulness rhythms. In this study, to minimize these influences, experiments were initiated at the same time of day in all cases. The subjects were instructed on adjustments to daily activities, such as maintaining appropriate sleep time from 2-3 days before the day of the experiment. Therefore, the sleep time and post-prandial period on the experimental day did not differ among the vibration exposure conditions. However, since experiments were initiated at 20:00, daytime activities may also have affected the results. Although the subjects were instructed to avoid excessive exercise, the degree of fatigue during the daytime may have affected the results. In the future, for a more accurate evaluation of the influences of exposure to whole-body vibration, more detailed adjustments of daily activities may be necessary.

As parameters of psychological stress, the salivary MHPG and HVA concentrations did not differ between before and after the exposure experiment irrespective of the presence or absence of exposure. MHPG and HVA reflect central noradrenergic neuronal activity and are also parameters of stress responses in healthy individuals [17]. The use of conventional biological parameters of stress measured by blood analysis requires blood collection, which can be a stress load itself, inducing vasoconstriction and an increase in blood pressure. Therefore, the correct measurement of stress by this method has been considered difficult. In this study, MHPG and HVA were used as parameters and were measured in salivary samples. Since the collection of saliva causes no physical pain and can be readily performed in a short time, this method was useful. However, the MHPG concentrations observed in this study were higher than those in previous studies. This may be associated with the psychological state of the subjects placed in a special experimental environment, and differences in the measurement method, which was HPLC in this study and gas chromatography/mass spectrometry in the report by Mass et al. [18] and other previous studies. Concerning the absence of changes in MHPG in this study, a previous study showed no activation of the noradrenergic nervous system and no increase in the MHPG concentration in the prefrontal area during a simple addition task [19]. The relatively high concentration of MHPG in this study, therefore, may not be due to the instruction given to the subjects, i.e., to stare at a black dot. Further studies on changes in parameters of psycho-
logical stress should take into consideration psychological influences and work loads.

REFERENCES