Variation of Floor-to-Head Transmissibility in Seated Human during Prolonged Driving Simulation*

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Abstract
In this study, the effects of prolonged exposure to whole-body vibration (WBV) on human physical response were investigated. In the experiments, the eight male subjects participated in a two hour driving simulation while being exposed to vertical random vibration. Five transmissibilities were obtained at thirty-minute intervals throughout the simulation. As the subjects viewed the driving simulation on a screen, they controlled the speed and direction with pedals and a steering wheel, respectively, although the vibration was stable and independent of the driving operation. Transmissibility was evaluated as the root-mean-square of transmissibility ($T_{rms}$), which was introduced to assess the amplitude of transmissibility within the frequency range of interest. The results showed that $T_{rms}$ of the head transmissibility in the z-axis over time does not change significantly at the frequency range of interest (2–8 Hz) and that the change in $T_{rms}$ depends on the test subject. However, when the magnitude of $T_{rms}$ at the end of the two-hour driving simulation (“120 minutes”) is compared with that at the beginning (“0 minute”) in the same frequency band (2–8 Hz), $T_{rms}$ tended to decrease over time. In particular, a significant difference between the two conditions was observed in the vicinity of the ±10% frequency range around the natural frequency. In addition, the changes in $T_{rms}$ under conditions of with and without vibration were compared. Although the head transmissibility changed after exposure to WBV, the head transmissibility without vibration exposure showed no significant change.

Key words: Whole-Body Vibration, Head Transmissibility, Driving Simulation, Natural Frequency

1. Introduction
In general, people are exposed to whole-body vibration (WBV) for most days of their lives. It is reasonable to assume that when people are exposed to WBV for a long time, the vibration contributes to changes in the human sensory system and causes discomfort, fatigue, and physical pain (1)-(8). To examine these cause–effect relationships, several studies have investigated the physiological reactions on the human body using HRV (heart rate variability) and SEMG (surface electromyography) (2-6). In addition, these studies have focused on investigating the progression of muscle fatigue with WBV and the interaction between activities in the sympathetic and parasympathetic nervous systems with WBV.

However, the relationship between WBV and physiological reactions on the human body is still unclear. Furthermore, when the effect of vibration on the human response is
considered, it is necessary to investigate the change in physical as well as physiological reactions. To observe the physical reactions between WBV and human response, usually acceleration is taken into account in the field measurements. The acceleration data measured at the input (seat or floor) and the output (head) can be summarized in terms of transmissibility, i.e., seat-to-head transmissibility or floor-to-head transmissibility. Transmissibility is defined as the movement at any point on the body (head) that is related to the magnitude of the input vibration at the seat or floor. It provides the basis for understanding the change of physical responses of the seated human to WBV.

Transmissibility in published reports has focused on changes in human response under various experimental conditions involving seated posture, excitation frequency and magnitude, and type of excitation \(^{7-15}\). These experiments have investigated human response when subjects were exposed to WBV for a short time. When the effect of vibration on the human body is considered, it is important to investigate the changes in human response due to prolonged exposure to WBV from the viewpoint of physical reactions.

However, it is difficult to investigate the changes in response of a seated human exposed to WBV in the field measurement because such response can be affected by human behaviors and environmental conditions while driving a car. The physical load or body stress of subjects increases in the field measurements. It is also difficult to obtain accurate data because the posture of subjects and the amplitude of input vibration can not be controlled in the field measurements. Moreover, from the viewpoint of human fatigue, an assessment of transmissibility is necessary to understand if the transmissibility of a seated human exposed to WBV changes over time. In this study, we investigate changes in human response over time as test subjects participating in a two-hour driving simulation were exposed to vertical random vibration.

2. Method

2.1 Experimental procedure

The subjects were seated in a car seat installed on a vibrating platform, as shown in Figure 1(a). They were permitted to adjust their seat to a natural driving position, as shown in Figure 1(b). They performed the driving simulation for two hours. They did not wear the shoulder harness during simulation. They put their hands on the steering wheel and their feet on the floor except when operating the pedals (accelerator and the brake). A screen was installed 3 m in front of the vibrating platform. They controlled their speed with the pedals and controlled direction with the steering wheel, although the vibration was stable and independent of the driving operation.

Furthermore, to reduce the mental stress in all subjects, during the simulation, they were allowed to participate in simple conversations, listen to music and control the level of the driving simulation. Five samples were obtained at thirty-minute intervals during the simulation. In each sample, the transmissibility was measured five times consecutively, which took a total of approximately five minutes.

To examine the change in the transmissibility for the “with car seat” condition, it is necessary to compare it with that for the “without car seat” condition. The transmissibilities were taken twice just before and immediately after the two-hour driving simulation. The subjects were seated in a rigid seat installed on a vibrating platform, as shown in Figure 1(d). They sat upright with their hands lightly resting on their thighs, without a backrest and their feet supported, and looked straight ahead.
2.2 Subjects and measurement condition

Eight healthy male subjects participated in the experiment. Before the experiment, the purpose of this study was explained to all subjects, who had given their consent for participation. Experiments were approved by the Research Ethics Committee in Tokyo Metropolitan University (No.20-6). The physical characteristics of subjects are presented in Table 1. The subjects aged between 23 and 42 years. Their body mass was between 58.5 and 72.0 kg and their height was between 164 and 179 cm.

<table>
<thead>
<tr>
<th></th>
<th>Age (year)</th>
<th>Mass (kg)</th>
<th>Stature (cm)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>70.5</td>
<td>177.9</td>
</tr>
<tr>
<td>B</td>
<td>23</td>
<td>72.0</td>
<td>176.4</td>
</tr>
<tr>
<td>C</td>
<td>21</td>
<td>63.5</td>
<td>168.0</td>
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<tr>
<td>D</td>
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<td>65.0</td>
<td>167.5</td>
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<tr>
<td>E</td>
<td>22</td>
<td>59.0</td>
<td>179.0</td>
</tr>
<tr>
<td>F</td>
<td>32</td>
<td>71.0</td>
<td>166.6</td>
</tr>
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<td>G</td>
<td>24</td>
<td>58.5</td>
<td>171.5</td>
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<tr>
<td>H</td>
<td>42</td>
<td>65.0</td>
<td>164.7</td>
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<p>| | | | |</p>
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<th></th>
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<tbody>
<tr>
<td>Mean</td>
<td>26</td>
<td>65.5</td>
<td>171.45</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>7.2</td>
<td>5.3</td>
<td>5.6</td>
</tr>
</tbody>
</table>

An electromagnetic vibrator (Model F-200 BM/A, EMIC Ltd., Japan) was used to generate vertical random vibration. To maintain the constant power spectrum density of
input vibration at the frequency of 1 to 30 Hz, the input vibration signal was regenerated by the signal processing system (Labview, NI Ltd, USA), and we also confirmed that the magnitude of input vibration concerned with time passage was stable. The magnitude of vibration was 0.2–0.3 m/s² in r.m.s. and the input vibration signal and magnitude were determined by referring to the floor vibration while driving the car. The duration of the exposure to WBV was two hour, which is within the accepted range provided in ISO13090-1(1998)(17). Acceleration data was acquired using the multi-channel data acquisition systems (Type Dewtron-3016, Austria). The acceleration in the z-direction was measured at the center of the vibrator surface using an accelerometer (Type 356A32, PCB Piezotronics, USA). The vibration of the heads of the test subjects was measured by the head-gear, which can measure tri-axial translations and tri-axial rotations of head motion with respect to the center of the head (15). Three tri-axial accelerometers were attached to the head-gear; one on the forehead (A) and one above each ear (B and C), as shown in Figure 1 (c).

2.3 Analysis methods

The vibration stimulus was in the vertical direction, and this study focuses on the floor-to-head transmissibility. The translational and rotational accelerations of the heads of test subjects were estimated from three tri-axial accelerometers on the basis of rigid body assumptions of the head.

We assumed that the responses were measured at multiple points (n=3) on the rigid body.

\[
\begin{bmatrix}
\ddot{x}_1 \\
\ddot{y}_1 \\
\ddot{z}_1 \\
\vdots \\
\ddot{x}_n \\
\ddot{y}_n \\
\ddot{z}_n
\end{bmatrix} = \begin{bmatrix}
1 & 0 & z_1 & -y_1 \\
1 & -z_1 & 0 & x_1 \\
1 & y_1 & -x_1 & 0 \\
\vdots & \vdots & \vdots & \vdots \\
1 & 0 & z_n & -y_n \\
1 & -z_n & 0 & x_n \\
1 & y_n & -x_n & 0
\end{bmatrix} \begin{bmatrix}
\ddot{x}_c \\
\ddot{y}_c \\
\ddot{z}_c
\end{bmatrix}
\]

\[U_n = [R]U_c \]  \hspace{1cm} (1)

where \(U_n\) (3n×1) indicates the accelerations of three tri-axial accelerometers, \(U_c\) indicates the acceleration at the geometrical center of the head (6×1), and \([R]\) indicates the transformation matrix (3n×6) consisting of \(x_i\), \(y_i\) and \(z_i\) which are coordinates of accelerometer locations relative to the center.

The method of least squares is applied to the Eq.(1) to estimate \(U_c\) from \(U_n\):

\[U_c = \left([R]^T[R]\right)^{-1}[R]^T U_n\]  \hspace{1cm} (2)

Equation (2) is applied to the time domain data. The acceleration in the z direction, \(\ddot{z}_c\), can be obtained from \(U_c\). The time domain data of \(\ddot{z}_c\) is converted to the frequency domain by Fourier transform with the Hanning window applied. The analysis was performed in the 2-20 Hz frequency band with a resolution of 0.12 Hz.

Floor-to-head Transmissibility is usually estimated by:

\[G(f) = \frac{S_{ab}(f)}{S_{aa}(f)}\]  \hspace{1cm} (3)

where \(G(f)\) is the floor-to-head transmissibility, \(S_{ab}(f)\) is the cross spectrum density between the input (Floor : \(a\)) and the output (head : \(b\)), and \(S_{aa}(f)\) is the power spectrum density of the input (Floor : \(a\)).
The following procedure was applied for evaluating the variation:

The averaged transmissibility \( \overline{G(f)} \) was calculated as a complex arithmetic mean, where \( N \) is the number of transmissibilities (\( N=5 \)):

\[
\overline{G(f)} = \frac{1}{N} \sum_{i=1}^{N} G_i(f)
\]

(4)

In this study, the root-mean-square of transmissibility \( T_{rms} \) is formulated to assess the amplitude of transmissibility within the frequency range of interest and given by

\[
T_{rms} = \left[ \frac{1}{n} \sum_{k=1}^{n} \left| G(f_k) \right| \right]^{1/2}
\]

(5)

where \( \left| G(f_k) \right| \) is the modulus in the averaged transmissibility at a particular frequency \( f_k \), and \( n \) is the number of frequency lines within the range of interest.

To determine the change in modal parameters over time, curve-fit is applied to each data to estimate the natural frequencies and damping ratios (16).

The frequency response function (FRF) under general viscous damping system can be represented as follows.

\[
G(\omega) = \sum_{r=1}^{n} \left\{ \frac{U_r + jV_r}{j(\omega - \omega_r) + \sigma_r} + \frac{U_r - jV_r}{j(\omega + \omega_r) + \sigma_r} \right\} + \frac{C}{\omega^2} + D
\]

(6)

where \( \omega_r, \sigma_r, U_r, V_r \) and \( n \) represent the \( r \)-th damped natural frequency, \( r \)-th modal decay ratio, real part of residue, imaginary part of residue, and number of degrees of freedom in the frequency band of interest, respectively. The \( C/\omega^2 \) and \( D \) are respectively the lower and upper residual terms modeling the influence of the out of band modes in the considered frequency band. In this study, the modal parameters are found by an iterative procedure based on the non-linear least squares approach.

For “with car seat” condition, the transmissibility was measured between the floor and head. Therefore, it is noted that when we evaluated the transmissibility, the result involved the effect of seat dynamics. When the subjects were seated on the seat pad installed in the car seat for a long time, they felt discomfort at the buttocks-seat pad interface due to the fact that the size of seat pad is large and the core material of the seat pad was rigid, where the seat pad measures the acceleration at the interface of seat surface and human body. To reduce the discomfort caused to the subjects during prolonged driving simulation, the transmissibility was measured between the floor and head. Statistical analysis of the data was performed with the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA). The Dunnett test was used, and multiple comparisons were performed to assess the change in \( T_{rms} \) with respect to time passage. In tests, \( p < 0.05 \) was accepted as the minimum for significance.
3. Results

To examine the change in the head transmissibility of a seated human exposed to WBV over time, the subjects participated in a driving simulation for two hours while being exposed to vertical random vibration.

3.1 Variation in the head transmissibility in the z-axis over time

Figure 2 shows the changes in five transmissibilities evaluated by measurements repeated five times at thirty-minute intervals throughout the simulation for subjects E and F. It shows that the change of the transmissibility is mainly observed around the resonant frequency (2-8 Hz). Although the variation in transmissibility over time is observed for all subjects, the magnitude of variation around the resonant frequency depends on each subject. To determine the change in resonant frequency over time, the curve-fit is applied to each data to estimate the modal parameters, i.e., natural frequencies and damping ratios (16). It is clear that the variation in the natural frequency for all subjects is small (within 0.7 Hz). Table 2 shows the damping ratio in each sample obtained by curve-fit. In addition, it shows that the damping ratios concerned with time passage do not change significantly for all subjects. To assess the amplitude of the transmissibility within the frequency range of interest (2-8 Hz), the transmissibility was evaluated as the root-mean-square of transmissibility ($T_{rms}$) in Figure 3. Figure 3 shows that $T_{rms}$ over time does not follow an obvious trend. However, when the magnitude of $T_{rms}$ for “120 minutes” is compared with that for “0 minute”, $T_{rms}$ tends to decrease in seven of the eight subjects, although the change is not remarkable.

![Fig. 2 Change in five transmissibilities over time for two subjects (2~20 Hz)](image)

<table>
<thead>
<tr>
<th>Time</th>
<th>Subject</th>
<th>0 min ($\zeta_0$)</th>
<th>30 min ($\zeta_{30}$)</th>
<th>60 min ($\zeta_{60}$)</th>
<th>90 min ($\zeta_{90}$)</th>
<th>120 min ($\zeta_{120}$)</th>
<th>$\Delta\zeta_{\text{max}}$</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>0.130</td>
<td>0.136</td>
<td>0.135</td>
<td>0.134</td>
<td>0.135</td>
<td>0.006</td>
<td>0.0023</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.196</td>
<td>0.201</td>
<td>0.188</td>
<td>0.192</td>
<td>0.201</td>
<td>0.008</td>
<td>0.0056</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.171</td>
<td>0.205</td>
<td>0.165</td>
<td>0.176</td>
<td>0.197</td>
<td>0.034</td>
<td>0.0172</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>0.161</td>
<td>0.156</td>
<td>0.165</td>
<td>0.154</td>
<td>0.148</td>
<td>0.013</td>
<td>0.0065</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>0.154</td>
<td>0.144</td>
<td>0.149</td>
<td>0.153</td>
<td>0.161</td>
<td>0.010</td>
<td>0.0063</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>0.164</td>
<td>0.171</td>
<td>0.168</td>
<td>0.179</td>
<td>0.197</td>
<td>0.033</td>
<td>0.0130</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>0.174</td>
<td>0.170</td>
<td>0.178</td>
<td>0.177</td>
<td>0.187</td>
<td>0.013</td>
<td>0.0063</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0.155</td>
<td>0.143</td>
<td>0.139</td>
<td>0.134</td>
<td>0.144</td>
<td>0.021</td>
<td>0.0077</td>
</tr>
</tbody>
</table>
3.2 Variation in the vicinity of the ±10% frequency range around the natural frequency

Although $T_{rms}$ tends to decrease at the frequency range of interest (2–8 Hz) after exposure to WBV for “120 minutes”, a significant difference is not observed for each subject. Therefore, we observed the variation in the vicinity of natural frequency in Figure 4. Figure 4 shows that when the amplitude of transmissibility for “120 minutes” is compared with that for “0 minute”, a significant change between these two conditions is observed. In addition, we evaluated $T_{rms}$ in the vicinity of the ±10% frequency range around the natural frequency. Although we also evaluated $T_{rms}$ in the vicinity of ±5%, ±15%, ±20% and ±25% frequency ranges, we observed the most significant change at the ±10% frequency range. Since the natural frequency changes slightly depending on time, the frequency range for evaluation of $T_{rms}$ is set up depending on the natural frequency at each time. For example, the natural frequency for “0 minute” in subject A is 4.39 Hz, where $T_{rms}$ is calculated from 3.95 Hz to 4.83 Hz. Next, the natural frequency for “30 minute” in subject A is 4.20 Hz, where $T_{rms}$ is calculated from 3.78 Hz to 4.62 Hz.

Table 3 shows $T_{rms}$’s in the vicinity of the ±10% frequency range around the natural frequency, and each sample is evaluated by the multiple comparisons in the statistical analysis compared with “0 minute”. The results indicate that when we observed the change in $T_{rms}$ in each sample compared with “0 minute”, after exposure to WBV for “120 minutes”, the changes in $T_{rms}$ in the seven subjects were significantly different except for subject B ($p<0.05$).

The significant change in $T_{rms}$ concerned with time passage differed for all subject. Subject E indicates significant change after exposure to WBV for “60 minutes”, whereas the subject A, F, and G indicate significant changes after exposure to WBV for “90 minutes”. Moreover, although subject C and D have two of the most significant changes throughout the simulation (subject C: 30 minutes and subject D: 60 minutes), these changes did not sustain till the end of the experiment. On the other hand, subject H shows an opposite trend compared with other subjects.

Although the reason for this trend is unclear, we guess that all subjects were not able to maintain perfect driving posture for two hours, which would cause $T_{rms}$ to differ over time between subjects. Moreover, a preliminary study, we confirmed the intra-subject variation in seat-to-head transmissibility differed depending on each subject, which was measured the seat-to-head transmissibility within a day or over several days (15).

Overall, when $T_{rms}$ for “120 minutes” is compared with that for “0 minute”, $T_{rms}$ significantly decreased in six of the eight subjects ($p<0.05$).
(a) Around natural frequency for Subject E  (b) Around natural frequency for Subject F
Fig. 4 Enlarged view in the vicinity of the natural frequency between “0 minute” and “120 minutes” for two subjects

Table 3 $T_{\text{rms}}$ in the vicinity of the ±10% frequency range around the natural frequency

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time</th>
<th>0 min</th>
<th>30 min</th>
<th>60 min</th>
<th>90 min</th>
<th>120 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.444</td>
<td>3.342 (0.168)</td>
<td>3.305 (0.158)</td>
<td>3.237 (0.004**</td>
<td>3.210 (0.000**</td>
<td></td>
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<tr>
<td>B</td>
<td>2.632</td>
<td>2.4664 (0.000**)</td>
<td>2.646 (0.937)</td>
<td>2.573 (0.183)</td>
<td>2.588 (0.424)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3.203</td>
<td>3.177 (0.001**)</td>
<td>3.085 (0.936)</td>
<td>3.162 (0.614)</td>
<td>3.119 (0.003**)</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3.288</td>
<td>3.177 (0.078)</td>
<td>3.085 (0.001**)</td>
<td>3.086 (0.061)</td>
<td>3.076 (0.005**)</td>
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</tr>
<tr>
<td>E</td>
<td>3.699</td>
<td>3.620 (0.057)</td>
<td>3.430 (0.000**)</td>
<td>3.439 (0.000**)</td>
<td>3.029 (0.000**)</td>
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<tr>
<td>F</td>
<td>3.371</td>
<td>3.274 (0.264)</td>
<td>3.202 (0.063)</td>
<td>3.035 (0.000**)</td>
<td>2.950 (0.000**)</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>3.278</td>
<td>3.183 (0.273)</td>
<td>3.139 (0.064)</td>
<td>3.090 (0.009**)</td>
<td>3.074 (0.005**)</td>
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</tr>
<tr>
<td>H</td>
<td>3.211</td>
<td>3.350 (0.013*)</td>
<td>3.345 (0.012*)</td>
<td>3.413 (0.000**)</td>
<td>3.400 (0.000**)</td>
<td></td>
</tr>
</tbody>
</table>

※ Values in parentheses indicate the p-value for the multiple comparisons in statistical analyses compared with the “0 minute”: **: $p<0.01$, *: $p<0.05$.

4. Discussion

4.1 Comparison of change in head transmissibilities with and without the car seat

This study investigated changes in the response of seated humans due to prolonged exposure to WBV. The results indicate that changes in head transmissibility are mainly observed around the resonant frequency. However, it is difficult to ascertain whether the change in the head transmissibility was affected by changes in seat dynamics or changes in the test subjects themselves. To assess changes in the test subjects over time, the transmissibilities were taken twice just before and immediately after two hour driving simulation for the “without car seat” condition. Figure 5 shows two transmissibilities obtained “before” and “after” exposure to WBV for two hour for subject E and F; comparison reveals that the “after” has smaller amplitude than the “before”. This change between the two conditions is observed mainly at the high frequency range (10–20 Hz).
A possible reason for this change is that the dynamics of the rigid seat does not allow cut-off of the high frequency components of the vibration signals. On the other hand, the dynamics of the car seat may contribute to such cut-off\(^{(8)}\). Therefore, this study focuses on the change in head transmissibility in the vicinity of the ±10% frequency range around the resonant frequency. Evaluation of \(T_{rms}\) in Figure 6 shows that although the change in head transmissibility depends on each subject, the averaged \(T_{rms}\) of the “after” (\(T_{rms}=1.593\)) is approximately 6.6% smaller than that of the “before” (\(T_{rms}=1.698\)). When \(T_{rms}\) of the “after” is compared with that of the “before”, it was found to decrease in six of eight subjects. The \(T_{rms}\)’s of the “after” for all subjects were evaluated by the statistical t-test and compared with those of the “before”; the t-test was also applied to the \(T_{rms}\)’s for “120 minutes” compared with those for “0 minute” for the “with car seat” condition. In both cases, the \(p\)-value’s (“with car seat” \(p\)-value=0.029 and “without car seat” \(p\)-value=0.044) are smaller than the standard value of 0.05. Therefore, we confirmed that after exposure to WBV for two hours, head transmissibility changed because of change in the human condition.

(a) Transmissibilities for Subject E (b) Transmissibilities for Subject F

Fig. 5 Head transmissibilities obtained by “before” and “after” exposure to WBV for two hour for two subjects (2–20 Hz)

Fig. 6 \(T_{rms}\) obtained for each subject (and averaged) in the vicinity of the ±10% frequency range around the resonant frequency under “before” and “after” exposure to WBV for two hours

4.2 Comparison of change in head transmissibilities between with and without vibration

Although change in \(T_{rms}\) in the vicinity of the ±10% frequency range around the natural frequency is observed after exposure to WBV for two hour, it is necessary to compare this result with that of “without vibration” condition. In a preliminary study, we investigated the variation “within a day” in the seat-to-head transmissibility of a seated human\(^{(15)}\). For observation of variation “within a day” in seat-to-head transmissibility, the five
transmissibilities were obtained at two-hour intervals on the same day without vibration. In this study, nine subjects participated in the experiment, and each subject had four pairs of transmissibilities at two-hour intervals under “without vibration” condition. Therefore, when we observed changes in $T_{rms}$ under the “without vibration” condition, the averaged $T_{rms}$ was calculated from the data set $(9 \times 4)$. When the averaged $T_{rms}$’s of the “before” and “after” were compared under “without vibration” condition, no significant difference between these two conditions was observed (“before”: $T_{rms}=1.796$ and “after”: $T_{rms}=1.798$). The $T_{rms}$’s of the “after” for all subjects were evaluated by the statistical t-test and compared with those of the “before”. The $p$-value under the “without vibration” condition ($p$-value=0.932) is much larger than the standard value of 0.05. It is understood that when a seated human is not exposed to WBV, the $T_{rms}$’s of “before” and “after” for head transmissibility are not significantly different.

5. Conclusions

This study investigated the variation in head transmissibility in a seated human exposed to WBV over time. The following remarks are provided as a summary.

(1) Variation in the head transmissibility in the z-axis of over time

Changes in the head transmissibility in the z-axis with passage of time were observed around the resonant frequency. The change in the resonant frequency for all subjects is small (within 0.7 Hz). In addition, when the magnitude of the $T_{rms}$ at the end of the two hour driving simulation (“120 minutes”) is compared with that at the beginning (“0 minute”), $T_{rms}$ decreased in seven of the eight test subjects at the frequency range of interest (2–8 Hz).

(2) Variation in the vicinity of the ±10% frequency range around the natural frequency

When $T_{rms}$ is evaluated by multiple comparisons in statistical analysis compared with “0 minute”, after exposure to WBV for two hours, seven of the eight test subjects showed significant differences ($p< 0.05$). $T_{rms}$ tended to decrease in six of the seven subjects ($p< 0.05$).

(3) Comparison of change in head transmissibilities between with and without vibration

After exposure to WBV for two hours, head transmissibility changed because of changes in the human condition. On the other hand, when the test subjects were not exposed to WBV during the two hour simulation, head transmissibility did not change significantly.

This paper investigated the changes in the human response due to prolonged exposure to WBV from the viewpoint of physical reactions. On the basis of these results, further research is necessary to provide validation and verification under practical situations (real driving).

References