着座人体の姿勢パラメータと振動特性の関連性

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Relation between Index Values for Seated Posture and Vibration Characteristics of Human Body

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To interpret the influence of whole-body vibration (WBV) on a seated human body, its vibration characteristics need to be clarified. Several previous studies have shown that differences in seated postures can change vibration characteristics such as the resonance frequency and the resonance amplitude of seat-to-head transmissibility and driving-point apparent mass. However, these studies did not fully express the seated postures of their subjects. Although the evaluation of human exposure to WBV is specified by ISO 2631, the seated postures for experiments are not specified in an ISO standard. To make good use of the results of human vibration experiments, a technical report on the description of seated postures exposed to WBV was published in 2012 and is still being discussed. In this study, we have measured seated postures in vibration experiments and investigated the relation between these postures and the resonance frequencies of transmissibility and apparent mass. A vertical random vibration of frequency 2–30 Hz was used in the experiment. The experiments were performed with two seated postures, an upright posture and a relaxed posture. The performance of a single regression analysis and a multiple regression analysis suggested that lumbar curvature is related to these resonance frequencies.

Key Words: Whole-Body Vibration, Seated Posture, Transmissibility, Apparent Mass, Resonance Frequency

1. Introduction

People are exposed to whole-body vibration (WBV) in our daily lives. It is necessary to clarify the vibration characteristics of a seated human body to interpret the effects of WBV (e.g., lumbar pain, motion sickness and tiredness). Many studies on the vibration characteristics of seated human bodies have already been published. Table 1 lists some examples(1), (2), (3) of the studies on seat-to-head transmissibility in the vertical direction. In these studies, there are some variations in the resonance frequency. One of the reasons for the variations is thought to be the variation in the seated posture of each experimental subject. However, the seated postures of the subjects are not fully expressed in the previous studies. Although the evaluation of human exposure to WBV is specified by ISO 2631(4) and the standard values of dynamic characteristics and their modeling are specified by ISO 5982(5), the seated postures for the measurements of WBV are not specified in an ISO standard. To make good use of the results of the human vibration experiments, an ISO technical report(6) on the description of seated postures exposed to WBV was published in 2012 and is still being discussed. This study aims to measure seated postures in vibration experiments and to investigate the relation between the seated postures and the vibration characteristics.

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2. Index values for seated posture

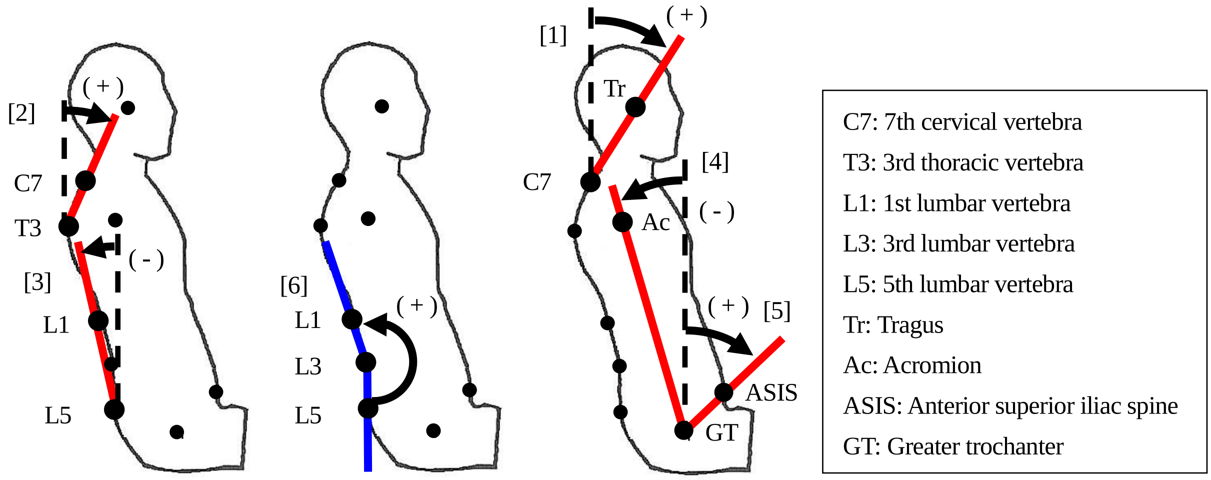
The 2012 technical report describes the notation for seated postures in human vibration experiments. The description of body angles is represented by a line connecting two points on the body of a human subject. To define the index values for the seated posture, we focus on the posture in the sagittal plane and adopt the sagittal flexion/extension of the lumbar and thoracic spines as well as the curvature of the lumbar spine. Table 2 shows these measurement points to express body angles. Figure 1(a) shows the index values based on the technical report. [2]Thoracic gradient and [3]lumbar gradient are described by the angle formed by the line connecting the two measurement points and the vertical line. Forward bending causes these index values to be positive. For example, the index values with positive or negative signs are shown in Figure 1(a). [6]Lumbar curvature is described by the angle formed by the line connecting the 1st and 3rd lumbar vertebrae and the line connecting the 3rd and 5th lumbar vertebrae. This is evaluated as 180° when three points (L1, L3 and L5) are in line and is larger than 180° in the posture of Figure 1(a).

Table 1 Seat-to-head transmissibilities of previous studies

Authors	Year	Resonance Frequency[Hz]
Hinz, Menzel	2010	5.3–6.5
M-Pransessh, Rakheja	2010	4.0–5.0
Rakheja, Dong	2010	4.0–6.0

Table 2 Measurement points for six index values

No.	Index value	Measurement points
[1]	Cervical gradient	Tragus, 7th cervical vertebra
[2]	Thoracic gradient	7th cervical vertebra, 3rd thoracic vertebra
[3]	Lumbar gradient	1st and 5th lumbar vertebra
[4]	Body gradient	Acromion, greater trochanter
[5]	Pelvic gradient	Anterior superior iliac spine, greater trochanter
[6]	Lumbar curvature	1st, 3rd and 5th lumbar vertebrae



(a) Index values based on technical report (b) New index values

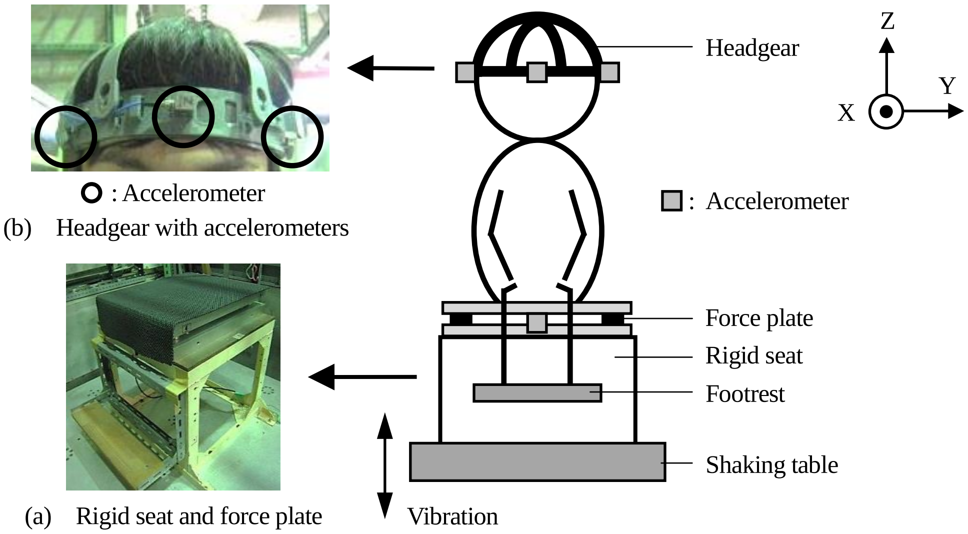
[1]Cervical gradient [2]Thoracic gradient [3]Lumbar gradient
[4]Body gradient [5]Pelvic gradient [6]Lumbar curvature

Figure 1 Index values for seated posture

Although the sagittal flexion/extensions of the cervical spine, body and pelvis are needed to express various seated postures, these are not specified in the technical report. [1]Cervical gradient, [4]body gradient and [5]pelvic gradient are defined with the measurement points of the technical report. Table 2 shows these measurement points to express body angles. The anterior superior iliac spine, which is not a measurement point in the technical report, is used to express the [5]pelvic gradient. As with the [2]thoracic and [3]lumbar gradients, the [1]cervical, [4]body and [5]pelvic gradients are described by the angle formed by the line connecting the two measurement points and the vertical line. Forward bending causes these index values to be positive. Figure 1(b) shows new index values. The index values for seated posture are numbered sequentially from the top of the spine.

3. Human vibration experiment

An experimental schematic is shown in Figure 2. The coordinate system conforms to ISO 2631(4). A subject sat on a rigid seat fixed to a shaking table and was excited in the vertical direction. The rigid seat has an adjustable footrest without a backrest. The acceleration of the subject's head was measured with three tri-axial accelerometers fixed on a headgear. The reaction force of the human body at the seat surface (driving-point) was measured using a force plate on the seat. By dividing the acceleration of his head and reaction force of the human body by the acceleration on the seat surface in the excitation direction, the seat-to-head transmissibility and the apparent mass were obtained. The seat-to-head transmissibilities of six degrees-of-freedom (three translational and three rotational degrees-of-freedom) were obtained by calculating nine translational transmissibilities measured by these accelerometers, assuming that the head was a rigid body. In this study, the seat-to-head transmissibilities in the vertical direction and the pitch rotational direction were used and called the vertical transmissibility and pitch transmissibility, respectively. However, we described only the vertical transmissibility in this paper. The following results and discussions on vertical transmissibility also basically apply to pitch transmissibility. An excitation wave was random at a frequency range of 2–30 Hz and a magnitude of 1.0 m/s^2 in r.m.s. The subjects were 20 healthy males. Their average height was 174 cm (167–183 cm, σ = 5 cm) and their average weight was 65 kg (47–81 kg, σ = 8 kg).



(b) Headgear with accelerometers

(a) Rigid seat and force plate

Figure 2 Experiment schematic

First, a subject sat upright and straightened his spine. His hands were placed on his thighs. He gazed at a point 3 m ahead. This posture is called the “upright posture” (Figure 3(a)). Second, he sat and eased the tension in his spine, which enabled the investigation of the difference in the vibration characteristics between different seated postures. The other conditions were the same as those for the upright posture. This posture is called the “relaxed posture” (Figure 3(b)). The seated posture of the subject was captured by two cameras before excitation to obtain the three-dimensional coordinates of the measurement points for the index values. The index values were calculated using these coordinates. We measured the vibration characteristics and the index values in the two seated postures.

We conducted measurements for each subject three times under the same conditions consecutively to confirm the reproducibility of the measured results and used averaged data of the three measurements as the result for a subject. The positions of the head, buttocks and femoral region of the subject were checked to ensure the measurement of the same posture. In particular, the position of his tragus was checked using a laser pointer. Before the experiment, we explained the experimental purpose and method to all subjects, and then obtained their consents for participation in the experiment. This experiment was approved by the ethics committee at Tokyo Metropolitan University.

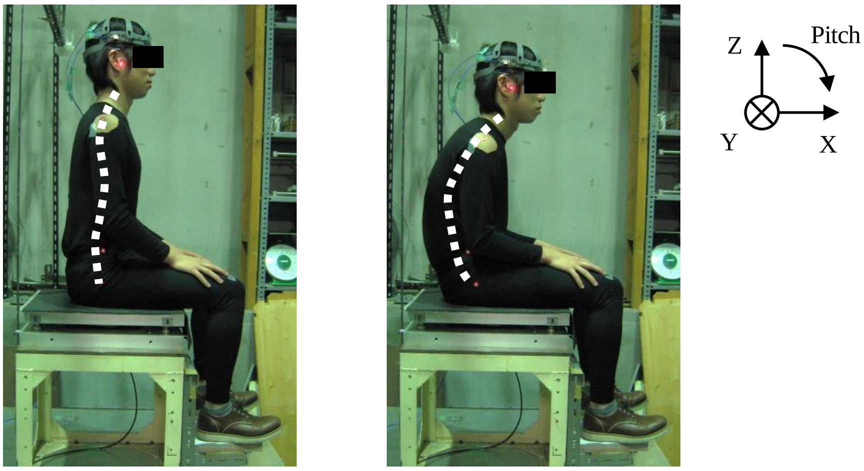
4. Results of human vibration experiment

4. 1 Vibration characteristics

Figure 4 shows the averages and ranges of the standard deviation of the vertical transmissibility and the apparent mass of all 20 subjects in two postures. Table 3 shows these first resonance frequencies in two postures. The resonance frequencies were regarded as those at the maximum amplitude near the resonance.

Regarding the vertical transmissibility, two resonances were observed in both postures. The first resonance frequency in the relaxed posture was slightly lower than that in the upright posture. The resonance amplitude in the relaxed posture was approximately 50% greater than that in the upright posture.

Regarding the apparent mass, the resonance frequency in the relaxed posture was slightly lower than that in the upright posture. The resonance amplitude in the relaxed posture was as large as that in the upright posture.

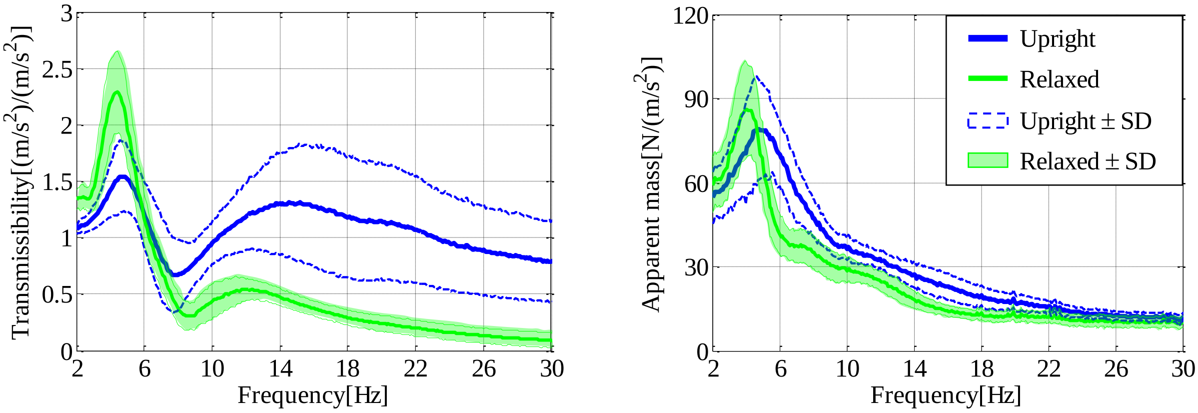


(a) Upright (b) Relaxed

Figure 3 Seated posture of subject

4. 2 Index values for seated posture

Figure 5 shows the averages and ranges of the standard deviation of the index values for seated posture of all 20 subjects in two postures. First, the [4]body gradient in the upright posture indicates that the subjects kept their trunks almost vertical as instructed. In the relaxed posture, the [4]body gradient remained almost vertical, the [2]thoracic gradient increased, while the [3]lumbar gradient and [6]lumbar curvature decreased; hence, the upper body was balanced. Second, with respect to the difference between the two seated postures, the [2]thoracic gradient, [5]pelvic gradient and [6]lumbar curvature exhibited large differences. Therefore, the posture and the change in posture of the subject in the experiment can be quantified by these index values. We can understand which parts change and how much they change.



(a) Vertical transmissibility (b) Apparent mass

Figure 4 Averages of vibration characteristics

Table 3 First resonance frequencies of average vibration characteristics [Hz]

	Upright	Relaxed
Vertical transmissibility	4.80	4.40
Apparent mass	4.80	4.00

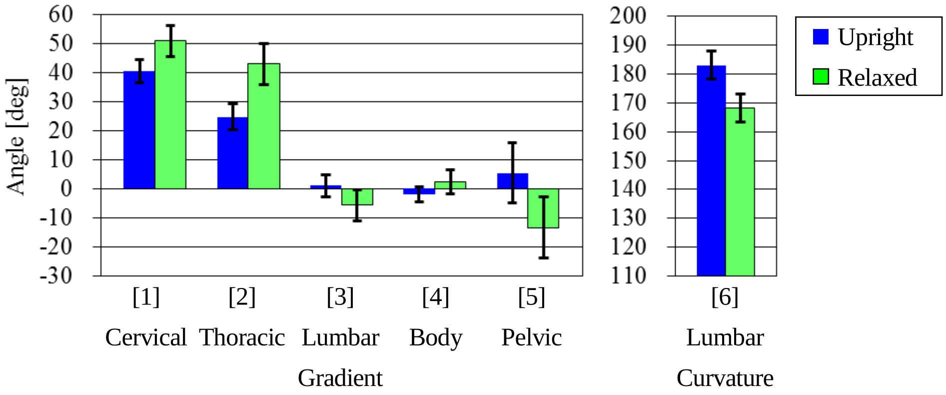


Figure 5 Averages of index values for seated posture

5. Discussion

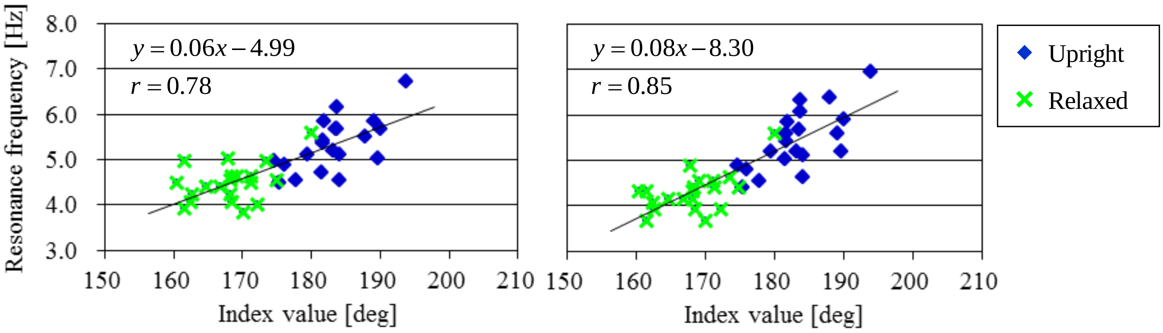
Although the averages of vibration characteristics and index values were used in the previous section, the relation between the index values for seated posture and the vibration characteristics was not investigated. Hence, we analyzed all experimental data to pay attention to the relation of each subject. In this study, the first resonance frequency was focused as the fundamental vibration characteristic and simply called the resonance frequency.

5. 1 Relation of index values for seated posture

Table 4 shows the correlation coefficients between the index value for seated posture and the resonance frequency with respect to 40 data-set, consisting of both the upright and relaxed postures of 20 subjects. The correlation coefficients of the [5]pelvic gradient and [6]lumbar curvature are higher than those of other index values for both vertical transmissibility and apparent mass. Figure 6 shows the correlation diagrams for resonance frequency and [6]lumbar curvature, which shows the highest correlation of all index values. Figure 6 confirms that these data are distributed almost linearly. Therefore, the resonance frequencies of vertical transmissibility and apparent mass are considered to be related to the [5]pelvic gradient and [6]lumbar curvature. The reason for the decreases in these resonance frequencies is thought that the backward tilt of the pelvis and the increase of the curvature of the lumbar decreased the spinal stiffness in the vertical direction.

Table 4 Correlation coefficients between index value for seated posture and resonance frequency

	Gradient					Curvature
	[1]	[2]	[3]	[4]	[5]	[6]
	Cervical	Thoracic	Lumbar	Body	Pelvic	Lumbar
Vertical transmissibility	−0.59	−0.61	0.50	−0.24	0.72	0.78
Apparent mass	−0.66	−0.70	0.55	−0.29	0.78	0.85



(a) Vertical transmissibility (b) Apparent mass

Figure 6 Correlation diagrams between [6]lumbar curvature and resonance frequency

5. 2 Relation of index values for seated posture and physical characteristics

It can be assumed that the resonance frequencies of vertical transmissibility and apparent mass are not determined by a single index of seated posture, but by multiple indices of the seated posture. In addition, the physical characteristics of the subjects, such as height, weight and body mass index (BMI), may affect the resonance frequencies. Therefore, it is necessary to perform a multiple regression analysis between the resonance frequency and two or more variables.

In this study, we performed a multiple regression analysis of these resonance frequencies using nine explanatory variables. They consisted of six index values for seated posture and three physical characteristics: height, weight and BMI. We investigated these variables by a stepwise method(7). Table 5 shows the results of the multiple regression analysis. The multiple correlation coefficients of vertical transmissibility and apparent mass are higher than the simple correlation coefficients in Table 4. In particular, the multiple correlation coefficient of apparent mass is the highest (0.92) of the two cases (a) and (b). Three explanatory variables are selected from the nine variables in two cases: [5]pelvic gradient, [6]lumbar curvature and weight. The partial regression coefficients of the [5]pelvic gradient and [6]lumbar curvature indicate that the increase in the curvature of the lumbar increases the resonance frequency. Those of the weight indicate that the increase in the subject's weight decreases the resonance frequency. Weight is selected as a variable that represents subject's physical characteristics. Compared to the standard partial regression coefficients in the two cases, the [6]lumbar curvature is the most significant explanatory variable. The standard partial regression coefficient is a normalized partial regression coefficient, and the magnitude of this value indicates the importance of the explanatory variable. Therefore, the resonance frequencies of vertical transmissibility and apparent mass are thought to be determined dominantly by the curvature of the lumbar. As a result of the multiple regression analysis, all two multiple correlation coefficients and the partial regression coefficients are evaluated as "significant" at the significance level of 1%.

Table 5 Multiple regression analysis

(a) Vertical transmissibility

Multiple correlation coefficient (P value)	0.86 (0.0000)			
	Explanatory variable			
	[5]Pelvic gradient	[6]Lumbar curvature	Weight	Invariable
Partial regression coefficient	0.02	0.04	−0.02	−0.13
Standard partial regression coefficient	0.33	0.51	−0.28	
P value	0.0082	0.0001	0.0025	

(b) Apparent mass

Multiple correlation coefficient (P value)	0.92 (0.0000)			
	Explanatory variable			
	[5]Pelvic gradient	[6]Lumbar curvature	Weight	Invariable
Partial regression coefficient	0.02	0.05	−0.02	−2.54
Standard partial regression coefficient	0.35	0.58	−0.24	
P value	0.0007	0.0000	0.0010	

6. Conclusions

Vibration experiments were conducted for 20 subjects in two postures. By expressing the seated postures with the index values for seated posture, the following can be concluded:

1) The first resonance frequencies of transmissibility in the vertical direction and apparent mass in the relaxed posture were slightly lower than those in the upright posture.

2) Posture change resulted in large differences in the thoracic gradient, pelvic gradient and lumbar curvature.

3) Single regression analysis showed that the first resonance frequencies were highly correlated with the pelvic gradient and lumbar curvature.

4) In the multiple regression analysis, the first resonance frequencies were expressed by the pelvic gradient, lumbar curvature and weight as explanatory variables. The lumbar curvature is the most dominant variable of the first resonance frequency, and weight is used to express the difference between subjects.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 24560300.

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