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VEHICLE AS A SAFETY FACTOR OF THE TRANSPORTATION ACTIVITY

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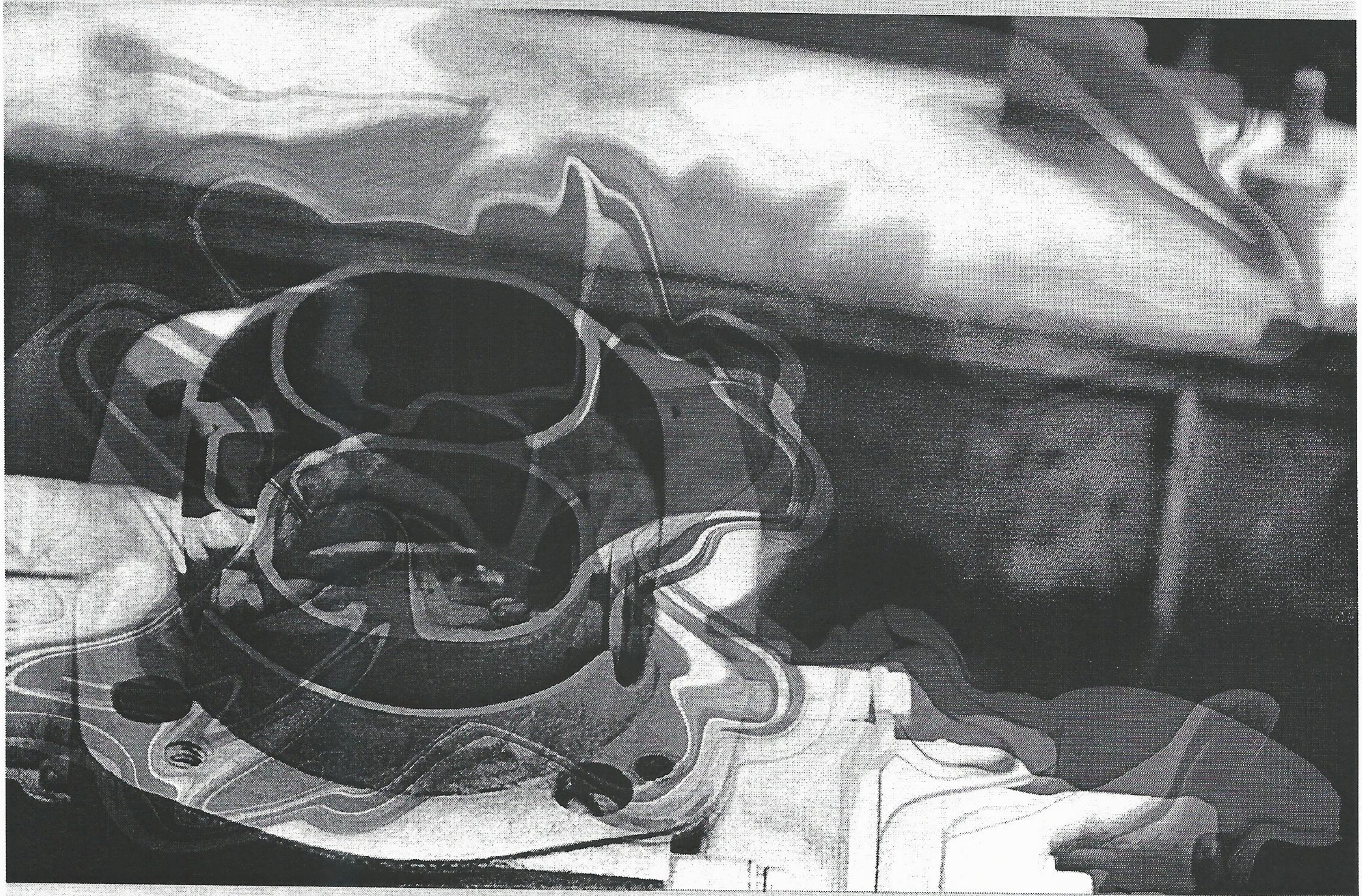

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October 9th - 10th, 2014
Kragujevac, Serbia

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VEHICLE AS A SAFETY FACTOR OF THE TRANSPORTATION ACTIVITY

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HUMAN BODY TRANSMISSIBILITY RESPONSE TO VERTICAL WHOLE BODY VIBRATION: ANTHROPOMETRICS EFFECTS – CASE STUDY SERBIA

ABSTRACT: The biodynamic response of human body exposed to vertical random whole body vibration in term of seat to head transmissibility function (STHT) is investigated in this study. The STHT response of 30 male human subjects exposed to three levels of the vertical random vibration (0.55, 1.75 and 2.25 m/s2 RMS) was measured in two sitting conditions (K – without seat backrest inclination, S – with seat backrest inclination) in the 0.3-30 Hz frequency range. The body mass revealed strong effect on the male STHT responses. The primary resonance frequency of heavier subjects was lower than that of the lighter subjects, while the peak magnitude was higher for the heavier subjects.

KEYWORDS: whole body vibration, Seat to Head Transmissibility Function (STHT), vertical vibration, body mass

INTRODUCTION

The influence of vertical, broadband, random, vibrations on the human body was examined through the seat-to-head transmissibility function (STHT). The biodynamic human response to whole body vibration (WBV) can be characterized using four biodynamic response functions. The driving point mechanical impedance (DPMI), apparent mass (APMS) and transfer mechanical impedance (TMI) are biodynamic functions often used to describe "to the body" biodynamic functions. The seat-to-head transmissibility function (STHT) describes the vibration transmitted through the body, [2].

The number of papers considering STHT is small in comparison with the number of papers considering DPMI. In this paper, the investigation of human body response to broadband random vibration was performed using STHT and these investigations were focused on vertical directional excitation.

From the synthesis of reported data on transmission of seat vibration to the head, it has been shown that seat-to-head vibration transmissibility is most significantly affected by the sitting posture, particularly the backrest contact. The study proposed different ranges of seat-to-head vibration transmissibility for back supported and back unsupported sitting postures. Apart from the sitting posture, the transmission of seat vibration may also be affected

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by various mass-, stature- and build-related anthropometric parameters. The effects of anthropometric parameters on the seated body STHT response to vibration have been investigated in even fewer studies.

MEASUREMENT AND ANALYSIS METHODS

An electrohydraulic motion simulator was used in the subjective experiment. The simulator was designed to provide the test bandwidth from 0,5 to 40 Hz with a total loading weight of 200 kg and to simultaneously obtain vertical and horizontal random excitation. The investigators had to define the frequency bandwidth and the magnitude of excitation.

Thirty male subjects, 43.862±9.866 years old, 179.897±6.608 cm tall, a mass of 85.586±14.297 kg, body mass index 26,417±3.990 and in good health, were tested. They were exposed to broadband random vertical excitation, Table 1.

Table 1 Table 1 Mean, standard deviation, minimum and maximum values of the selected anthropometric dimensions of the participants

	Minimum, Maximum, Mean (standard deviation)
Age, year	*18, 59, 43,9, 9.697*
Body mass, kg	*60, 113, 85.90, 14.153*
Height, m	*1.68,1,98,1.801,0.06588*
Body Mass Index	*18.937, 34.876, 26.452, 3.925*

The laboratory experiment was carried out to determine STHT (a complex ratio between complex head acceleration and complex seat acceleration, including magnitude of response function, phase function and coherency, and in the sitting position under broadband random vibration in the vertical direction. Spectral analysis was performed in the broadband frequency domain. The STHT functions were calculated using the Cross-spectral density [1] at a frequency resolution of 0,037 Hz. Test conditions (magnitude of excitation and seat backrest angle) was varied.

Detailed description of measurement set up is given in [2]. Subjects tested were sitting in a driving position with their hands on the steering wheel. Seat backrest angle was varied: position of backrest (K) with inclination angle of 14° with respect to vertical axis and position (S) with inclination angle of 0°. The excitation magnitude was also varied (0,55, 1,75 and 2,25 m/s^2 r.m.s.). The frequency range of excitation was 0,5-40 Hz. Thirty trained male subjects participated in the experiment with one-directional excitation.

DATA ANALYSIS

Figure 1 and figure 2 displays functions in the vertical direction for subjects exposed to vertical broadband whole body vibration (WBV). STHT functions have two or three resonances depending on the subject's characteristics. The first resonance (near to 5 Hz) corresponds to the whole body resonance [2, 3] and the second resonance (near to 14 Hz) corresponds to upper body resonance [2, 3], and if the third exists, it corresponds to foot resonance (20 Hz) [2, 3]. The spread of the results was caused by intersubject variability [1]. The influence of excitation magnitude on averaged STHT function for vertical broadband random excitation are given in Figures 3 and 4.

Figures 3 show the STHT function in the fore and aft direction increases in magnitude with respect to the increase of the excitation magnitude in frequency range below 8 Hz. A decrease in magnitude was observed in the frequency range of 8-18 Hz with respect to excitation level. At resonant frequencies the increase in excitation level caused the increase in STHT magnitude. The phase of STHT was also changed.

Data given in Figure 4 shows that the increase in excitation magnitude caused the increase in STHT magnitude in vertical direction in the low-frequency region, below the first resonance. At the second resonance, the differences between STHT magnitudes were the greatest, as well scattering data. The increase of excitation level caused the decrease of STHT magnitude at the second resonant frequency.

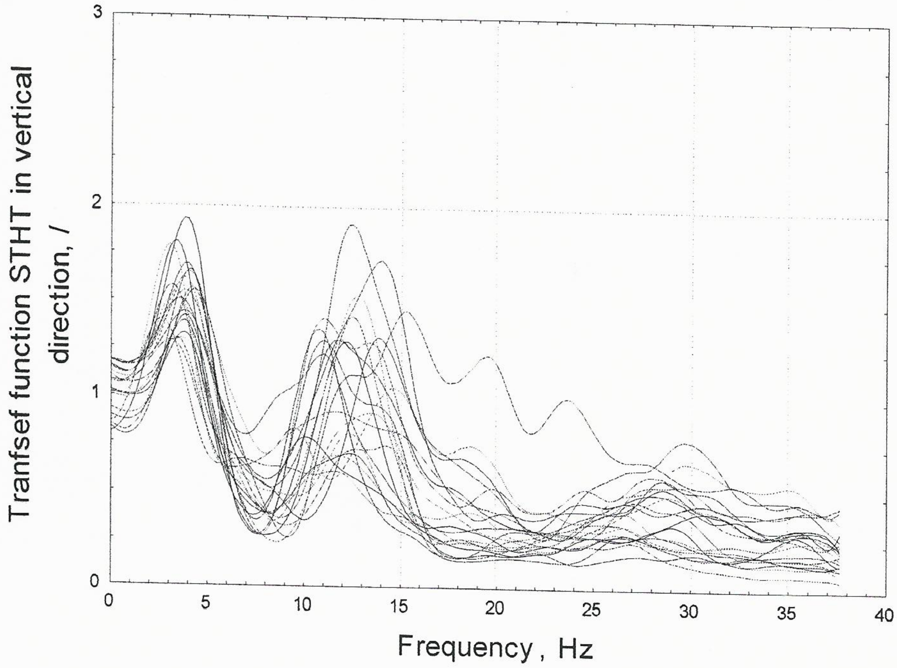

Figure 1 Transfer function *STHT magnitude in vertical direction, S backrest position, excitation 1.75 m/s² RMS*

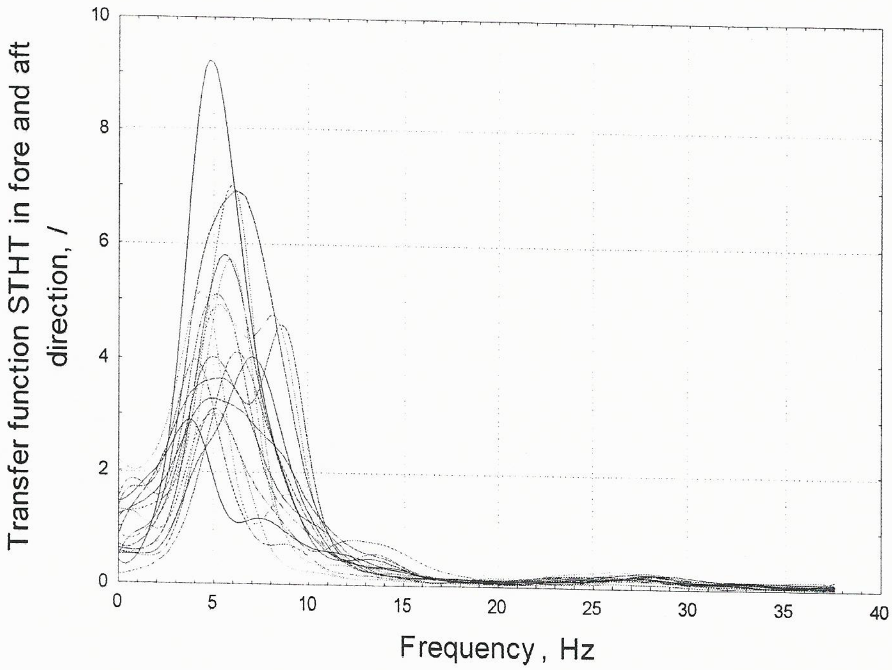

Figure 2 Transfer function *STHT magnitude in fore and aft direction, S backrest position, excitation 1.75 m/s² RMS*

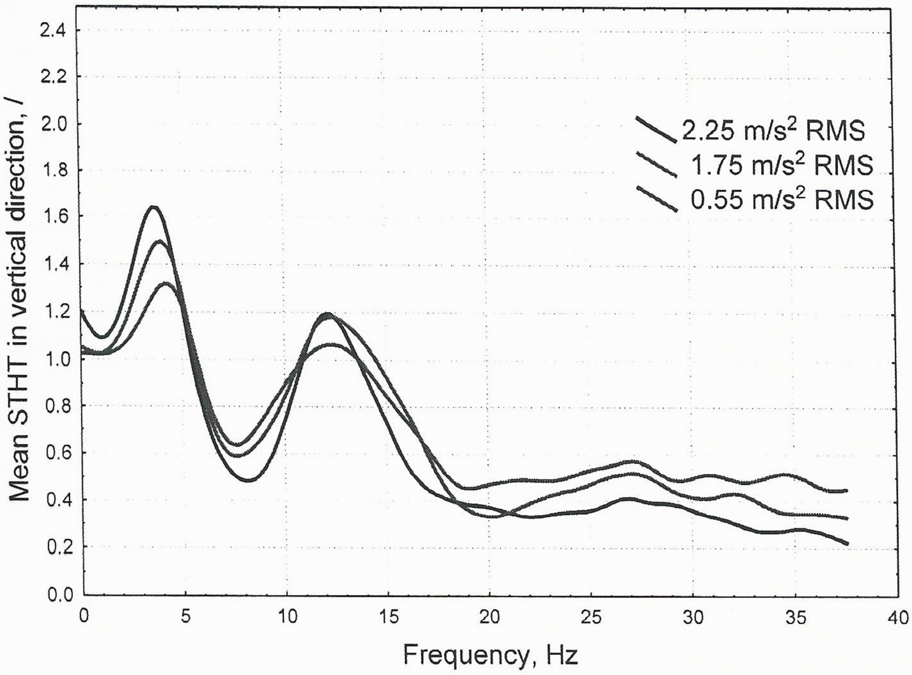

***Figure 3** Transfer function STHT mean magnitude in vertical direction, K backrest position*

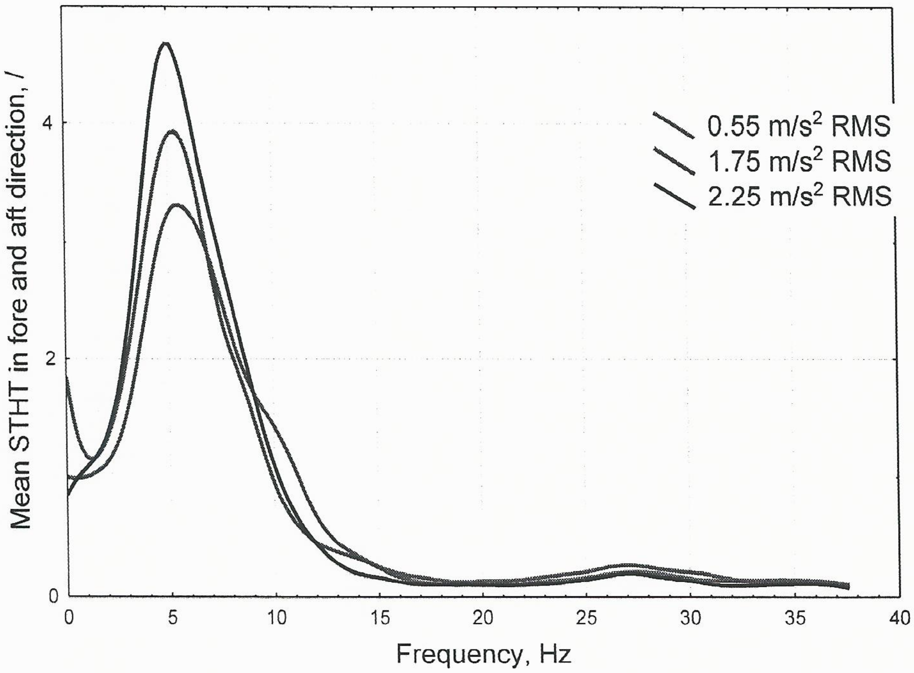

***Figure 4** Transfer function STHT mean magnitude in fore and aft direction, K backrest position, excitation 1.75 m/s2 RMS*

The comparisons suggest large inter-subject variations in the STHT magnitude as well as the primary resonance frequency. For vertical STHT responses, the primary resonance frequency varied from 3.8187 to 4.353 Hz for the K support, and was observed in the 3.7083 to 4.465 Hz range for the S sitting condition. The coefficient of variation (CoV) of the magnitude data ranged from 15.109% to 16.403% for the K support and 13.711% to 18.035% for the S support in the vicinity of the primary resonance frequency, Table 2.

The frequency corresponding to the peak fore-aft magnitudes varied from 4.8882 to 5.4632 Hz for the K support and 5.0118 to 5.7722 for the S support conditions. The fore-aft STHT responses revealed relatively higher scatter with CoV of the magnitude data ranging from 35.454% to 43.551 % for the K support, and 24.340% to 41.389% for the S support, table 2.

Table 2 Mean (standard deviation) of the peak STHT magnitudes and the corresponding frequencies of the 30 male subjects for the two sitting conditions and three levels of excitation.

Excitation, m/s² r.m.s.	*K seat backrest position*	*S seat backrest position*
	Peak STHT	
	Vertical direction	
0,55	*1.3712 (0.24729)*	*1.3531 (0.21683)*
1,75	*1.5683 (0.21504)*	*1.5765 (0.23821)*
2,25	*1.5625 (0.21838)*	*1.5917 (0.261098)*
	Frequency corresponding to peak vertical STHT	
0,55	*4.3538 (0.44653)*	*4.4654 (0.48821)*
1,75	*3.9465 (0.42359)*	*4.0292 (0.46202)*
2,25	*3.8187 (0.44275)*	*3.7083 (0.52413)*
	Fore and aft direction	
0,55	*4.1283 (1.00486)*	*3.7322 (1.35024)*
1,75	*5.2121 (1.56796)*	*4.6400 (2.02077)*
2,25	*4.9024 (2.02906)*	*4.4159 (1.56561)*
	Frequency corresponding to peak vertical STHT	
0,55	*5.4632 (1.30606)*	*5.7722 (0.99812)*
1,75	*5.1737 (0.68786)*	*5.4471 (1.06836)*
2,25	*4.8882 (0.63726)*	*5.0118 (0.63824)*

The influence of excitation on prime resonance in vertical direction (Z) and in fore and aft direction is shown in figure 5. Change of seat backrest inclination has significant effects on resonance in vertical and fore and aft direction. Differences are substantially higher in fore and aft direction.

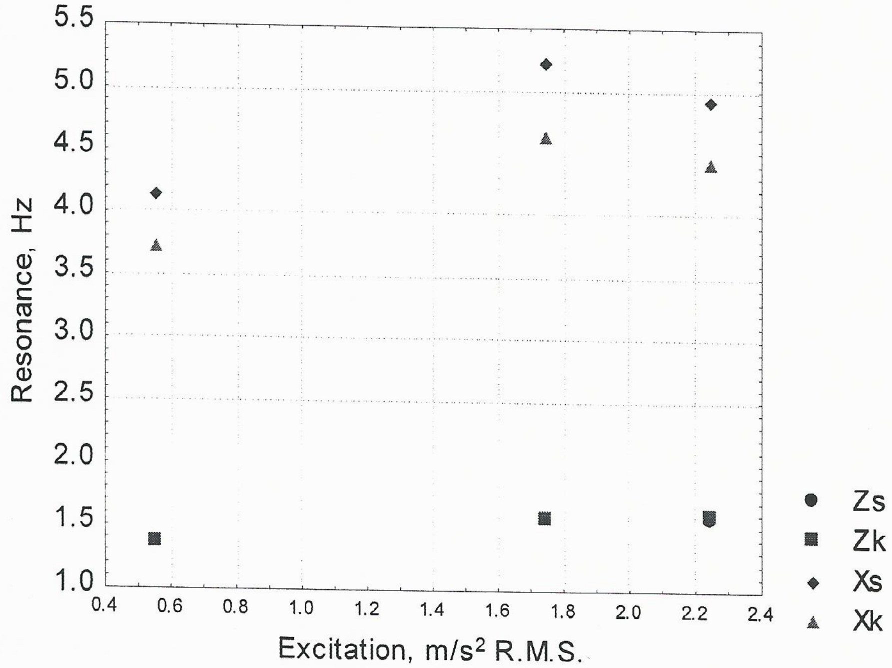

Figure 5 The influence of excitation and seatbackrest position on the first resonance in vertical (Z) and fore and aft direction (X)

The influence of excitation on magnitude in vertical direction (Z) and in fore and aft direction is shown in figure 6. Change of seat backrest inclination has significant effects on STHT magnitude in vertical and fore and aft direction. Differences are substantially higher in fore and aft direction. Increase of excitation magnitude caused reduction of STHT magnitude.

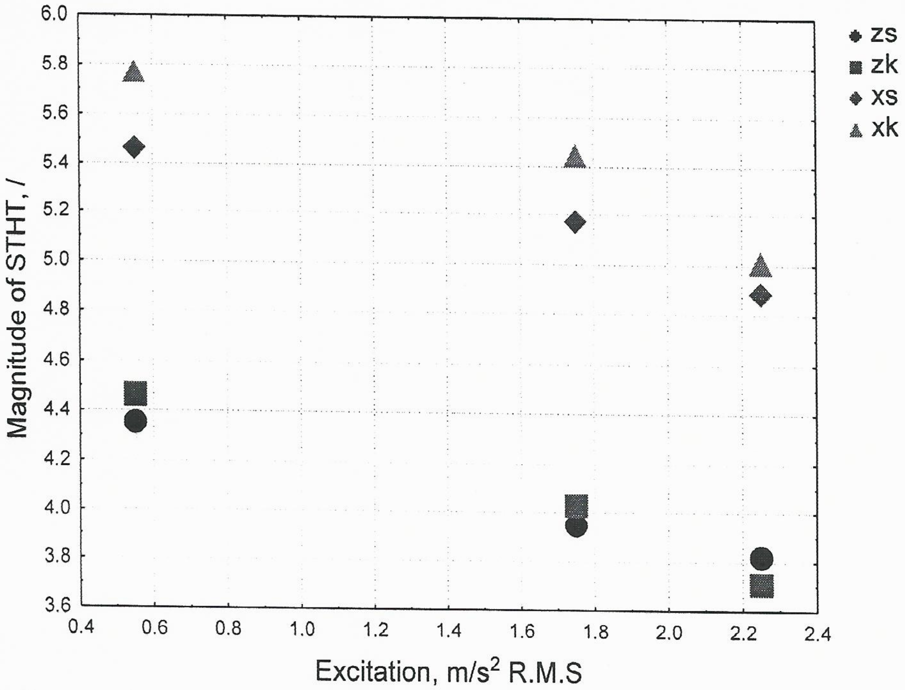

Figure 6 The influence of excitation and seatbackrest position on the magnitude of STHT in vertical (Z) and fore and aft direction (X)

Group of male subjects G70 mass in the range 66-75kg were analyzed in order to compare obtained results with results published in [3]. In [3] investigation was performed on group of male and group of female subjects. Effects of gender will be aim of future investigation. Comparison is conducted based on results obtained on group G70. Mass 71.4286 ±2.22125 kg, in the range 69 to 75 kg. Range of masses in the same as well in [3], but there is difference between anthropometry data.

Table 3 Descriptive statistics of G70

Variable	Mean	Minimum	Maximum	Std.Dev.
Mass, kg	71.428(	66.000(	75.000(	2.22121!
Stature, m	1.781:	1.720(	1.860(	0.04969(
Shoe number	42.125(	41.000(	43.000(	0.64087(
Age, year	39.375(	18.000(	52.000(	9.66492:
BMI	22.461(	20.522(	24.212:	1.42086

Table 4 Covariance of group G70

Variable	Mass, kg	Stature, m	BMI	Resonanc	STHTz, /
Mass, kg	6.33333:	-0.000000(	1.99465:	-0.550000(	-0.256667
Stature, m	-0.000000(	0.00152!	-0.038257	0.010000(	0.00112!
BMI	1.99465:	-0.038257	1.587968	-0.423644	-0.108569
Resonance, Hz	-0.550000(	0.010000(	-0.423644	0.25222:	-0.01411
STHTz, /	-0.256667	0.00112!	-0.108569	-0.01411	0.07774

DISCUSSION

The study, [1] employed 31 male and 27 female subjects with wide range of physical characteristics such as body mass (45.5–106.0 kg), stature (1.48–1.92 m), BMI (15.78–34.99 kg/m2), body fat mass (8.8–39.0 kg), lean body mass (34.1–77.5 kg) and hip circumference (88–116 cm), thereby facilitating the study of effects of anthropometry on the vertical and fore-aft STHT responses. Such wide variations in the anthropometric characteristics, in addition to the other contributory factors such as variations in the sitting posture, upper body-backrest contact and head orientations, most likely caused large variations in the primary resonance frequency, ranging from 4.13 to 6.00 Hz and 3.94 to 6.50 Hz for the NB and WB support, respectively, as observed from the vertical STHT responses. The fore-aft STHT responses also revealed broad variations in the frequency corresponding to the primary peak: 3.88 to 6.31 Hz and 3.56 to 6.06 Hz for K and S support, respectively.

In the presented study 30 male subjects took part with characteristics were: mass (60-113kg), stature (1.68-1.98cm), BMI (21.258-28.823 kg/m^2), age (18-59 years).

The vertical and fore-aft STHT peak magnitudes reduced substantially when sitting condition was changed from S support to K support. (Table 1,3). The effect of sitting condition on vertical STHT response was more pronounced near the secondary resonance as compared to the primary resonance (Figure 3 and 4). Previous studies relating to the effects of a back support also suggested that sitting with a back rest suppresses the peak vertical STHT magnitude considerably compared to that obtained when sitting without a back support [3,4]. A backrest serves as an important constraint that limits the upper body motion in the sagittal plane and changes the related muscles tension, while it also represents as an additional driving-point. The use of a back support thus alters the vibration transmission properties of the body considerably. Furthermore, a backrest constraint could limit the pitch motion of the upper body and thereby alter the fore-aft vibration of the head, which would also depend upon the sitting height and phase relationship between the pitch and fore-aft body modes. This effect was evident for the subjects as seen in Figure 1 and 2.
The softening effect was more evident with increase in excitation from 0.5 to 1.75 m/s2, while this effect was smaller with increase in excitation from 1.75 to 2.25 m/s2.

The results also revealed substantial variability in the STHT magnitudes near the primary resonance frequency (peak CoV of 113.711% and 18.035% of the vertical and fore-aft STHT magnitudes, respectively, with S support.

The vertical STHT responses of most of the subjects revealed the presence of a secondary resonance peak in the 8–14 Hz range (Figure 2). Furthermore, this secondary peak was more prominent in the presence of a vertical back support (S), as seen in Figure 2, which has also been reported in earlier studies [3,4]. The fore-aft STHT responses of most of the subjects also depicted peaks in the 3 to 5.7 Hz ranges. The majority of these low magnitude peaks, however, could not be clearly observed from the mean data due to large variations in the corresponding frequency and the averaging process. The mean STHT responses of subjects with widely different anthropometric characteristics thus cannot be used to interpret the influences of physical attributes of subjects including the gender. Moreover, the mean responses do not fully describe individual subject's responses to WBV.

CONCLUSIONS

The peak magnitudes of both the STHT responses (vertical and fore and aft direction) were not correlated with any of the anthropometric parameters, irrespective of the sitting condition and vibration excitation. However, the primary resonance frequency was weakly and negatively correlated with the selected anthropometric parameters.
Poor correlations of anthropometric parameters with the primary resonance frequency and the peak STHT magnitude may be due to a variety of reasons. Human body is a very complex system and there was large variations among the recruited subjects in body dimensions as well body type (endomorphic, mesomorphic and ectomorphic), type of muscle fibers (slow twitch and fast twitch) Human subjects generally maintained normal upright posture during the experiments, but it was difficult to control whether they were sitting with tensed or relaxed muscles, and with the progress of the experiments, some subjects might have changed their posture involuntarily. Little changes in muscle tension or posture could alter the primary resonance frequency and the corresponding magnitude (iIntrasubjective variability), [4,5,6]. The WBV-induced head motion is particularly sensitive to postural changes, due to associated changes in muscle tension in the abdominal region, which in turn changes the body stiffness and thus the natural frequency of the body. The position of the seat in the WBVVS was fixed with respect to the steering wheel, considering the average size of the subjects. However, body dimensions of the subjects varied enormously. Therefore, it was a little bit difficult to maintain same erect posture with same body stiffness, particularly for very short subjects when sitting with a back support. Finally, the postural changes would also contribute to orientation errors of the head accelerometer, which was monitored only visually in the present study.

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