3rd International Conference
„CONFERENCE ON ADVANCES IN SCIENCE AND TECHNOLOGY" COAST 2024
29 May - 01 June 2024 HERCEG NOVI, MONTENEGRO

INFLUENTIAL FACTORS ON THE RESPONSE OF A BODY EXPOSED TO MULTIAXIAL VIBRATIONS

Igor Saveljic [1], Slavica Macuzic Saveljic [2]
[1] Institute for Information Technologies, University of Kragujevac, Serbia
[2] Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

Corresponding author e-mail address: isaveljic@kg.ac.rs (I. Saveljic)

ABSTRACT:
Whole-body vibrations represent one of the causes of spinal disorders in humans. Prolonged exposure to multiaxial vibrations can lead to harmful consequences for the musculoskeletal system, while repetitive occurrences may result in the development of pathological changes in the spinal column. The biodynamic responses of seated passengers exposed to whole-body vibrations have been extensively studied in terms of the apparent mass or seat-head transfer functions across a wide frequency range of vibrations. In this work, the subjects were exposed to multiaxial vibrations. Seat-head transfer functions were determined in order to evaluate the biodynamic response of the body and influencing factors on the frequency response.

Keywords: *biodynamic responses, multiaxial vibrations, musculoskeletal system, transfer function*

---

1. INTRODUCTION

Vibrations in the car represent a key factor in driving that directly affects passenger comfort and can have a significant impact on human health. Uneven roads often generate vibrations that are transmitted to the car, and the sensation of these vibrations can significantly influence the perception of comfort [1]. Modern technologies in the automotive industry, such as impact absorption systems and adaptive suspensions, are designed to reduce these vibrations and improve the feeling of comfort during driving. However, there is also a significant impact of vibrations on human health. Prolonged exposure to vibrations can lead to various issues, including fatigue, back and neck pain, as well as other musculoskeletal problems [2]. This is particularly significant for professional drivers or individuals who spend extended periods of time in the car. Contemporary research focuses on developing innovative vibration management systems to enhance passenger comfort and reduce potential negative effects on health. Technologies such as active vibration control systems and smart suspensions play a crucial role in optimizing the driving experience and minimizing the impact of vibrations on human health [3], [4].

Exposure to vibrations elicits varying effects on the human body, ranging from mild discomfort to a reduction in work efficiency and disturbances in health [5]. Current

guidelines outlined in the international standard ISO 2631-1:1997 provide criteria for determining the tolerances of the human body exposed to whole-body vibrations. This standard, ISO 2631-1:1997, is employed for evaluating exposure to elevated levels of vibrations and impacts. The vibrations absorbed by the human body can induce muscle contractions, leading to muscular fatigue, particularly at resonant frequencies [6]. Resonance occurs in the thorax-abdominal system due to vertical vibrations within the 5 Hz - 10 Hz range (4 Hz - 8 Hz in the chest, 20 Hz - 30 Hz in the head, neck, and shoulders, and 60 Hz - 90 Hz in the eyes) [7].
Most everyday exposures to whole-body vibrations in a vehicle encompass vibrations in multiple axes. Through the analysis of research, it has been concluded that multi-axial vibrations induce greater discomfort compared to single-axis vibrations, whether they are vertical or longitudinal vibrations. Characterizing the biodynamic responses of the human body to multi-axial vibrations provides a better understanding of human reactions to real vibrations in a vehicle and contributes to the development of multidimensional biodynamic models.

2. METHDOS

To induce vibrations of varying amplitudes and frequencies, we employed an electro-hydraulic pulsator HP-2007, equipped with a car seat for subject exposure to vibrations. This apparatus has the capability to generate vibrations in two directions. A system of three-axis accelerometers, utilizing the AC102-1A accelerometer with a weight of 90 g, sensitivity of 100 mV/g, and a frequency range of 0.5 – 15,000 Hz, was mounted on the subject's spinal region. The measurement system utilized the 01dB-Metravib NetdB PRO-132 acquisition system. The experimental parameters included a sampling rate of 51,200 Hz, block duration of 80 ms, 4,096 samples, 2 averages, and a sampling step Δt = 0.0195 ms. Signal overlap was set at 75%. The frequency step was Δf = 0.390625 Hz, and the bandwidth was 39 Hz.

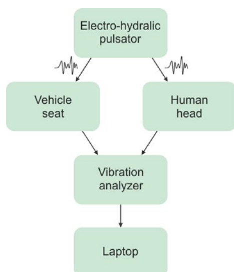

Fig. 1. Position of the three-axial accelerometers

20 male subjects participated in the experiment. Subjects were seated in an upright position with their hands on their thighs. At the same time, 6 acceleration signals were recorded (in the direction of the x, y and z axes for each measurement place). Subjects were exposed to random vibrations of the whole body for two excitation values 0.45 m/s^2 and 1.1 m/s^2 r.m.s., in the frequency range 0.1 Hz - 20 Hz, the most significant for studying the response of the human body according to the resonances of body parts

(Rasmussen , 1982). Also, at the same time, the angle of inclination of the seat back was varied, where the values were 90° and 110° in relation to the seat part of the seat.

3. RESULTS

Experimental investigations have produced many results, so only the most significant ones will be presented in the paper.

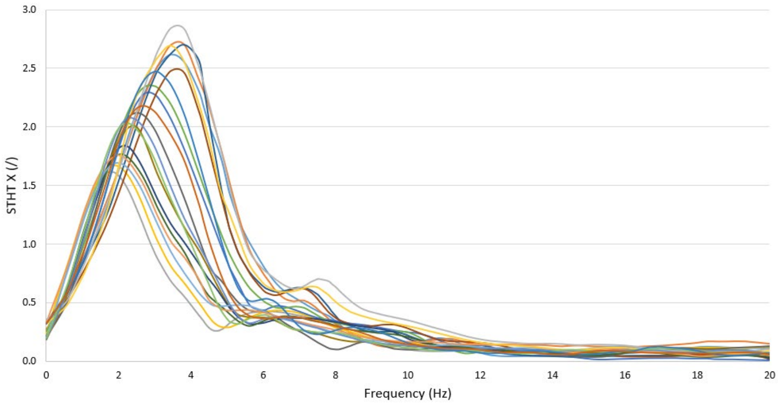

Fig. 2. STHT responses in the fore-and-aft direction for 20 subjects (excitation 0.45 m/s^2 r.m.s., angle of inclination of seat back 90°)

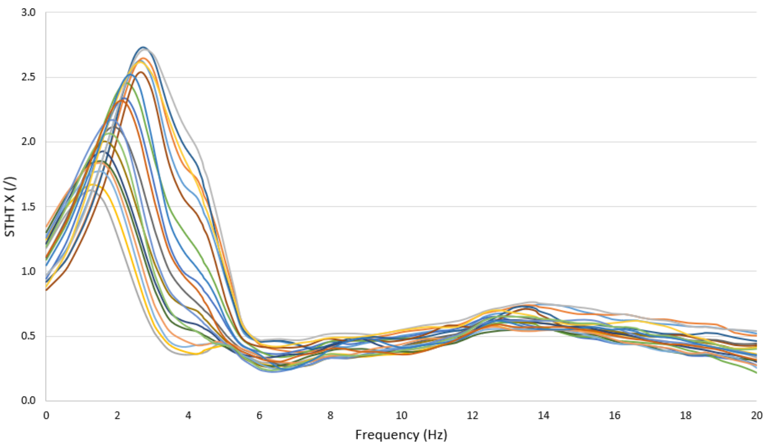

Fig. 3. STHT responses in the fore-and-aft direction for 20 subjects (excitation 1.1 m/s^2 r.m.s., angle of inclination of seat back 110°)

The highest resonant frequency of 2.66 Hz in the longitudinal direction was influenced by the excitation of 0.45 m/s^2 r.m.s. with a mean amplitude value of the STHT response of 1.96. For a seat backrest inclination angle of 110°, lower resonant frequencies of the

STHT response in the longitudinal direction were observed compared to a sitting angle of 90°. In the frequency range of 12 Hz - 14 Hz, there is a slight maximum, indicative of secondary resonance (Fig. 4).

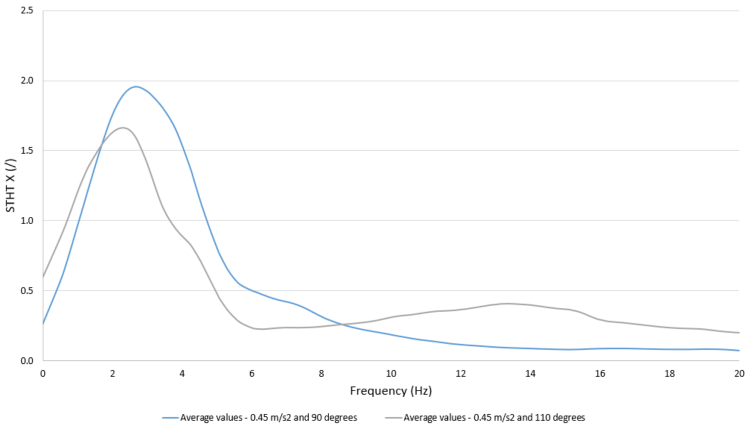

Fig. 4. Mean values of the STHT response in the fore-and-aft direction (excitation 0.45 m/s^2 r.m.s., angles of inclination of seat back 90° and 110°)

An excitation of 1.1 m/s^2 r.m.s. induced the highest resonant frequency of 2.35 Hz, with a mean amplitude value of the STHT response at 2.29 (Fig. 5). The obtained results demonstrate nonlinearity in the seat-driver system. Each increase in vibration amplitude leads to an increase in the amplitude of the STHT response and a decrease in the resonant frequency value. It can be concluded that, depending on the experimental conditions, the seat-driver system has the capability to dampen/amplify excitations.

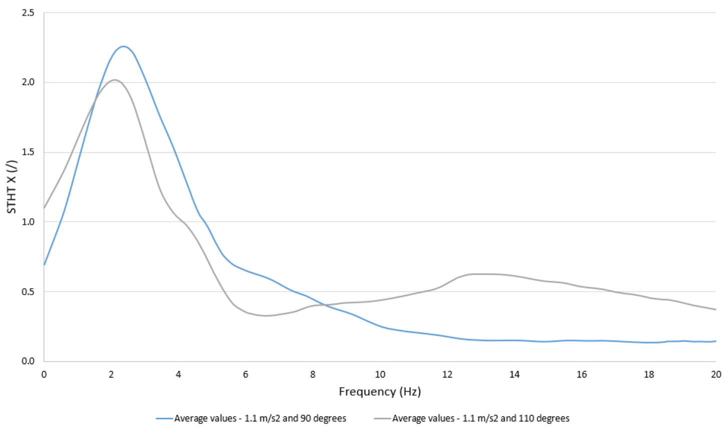

Fig. 5. Mean values of the STHT response in the fore-and-aft direction (excitation 1.1 m/s^2 r.m.s., angles of inclination of seat back 90° and 110°)

In the STHT response of the vertical direction, for an excitation of 0.45 m/s², the appearance of a second maximum in the frequency range of 8 Hz - 10 Hz was observed. Additionally, the highest resonant frequency of 3.60 Hz was noted, with a mean amplitude value of the STHT response at 1.57. For a seat backrest inclination angle of 110°, lower resonant frequencies of the STHT response in the longitudinal direction were observed compared to other sitting angles of 90°. In the frequency range of 12 Hz - 14 Hz, there is a slight maximum, indicative of secondary resonance (Fig. 6).

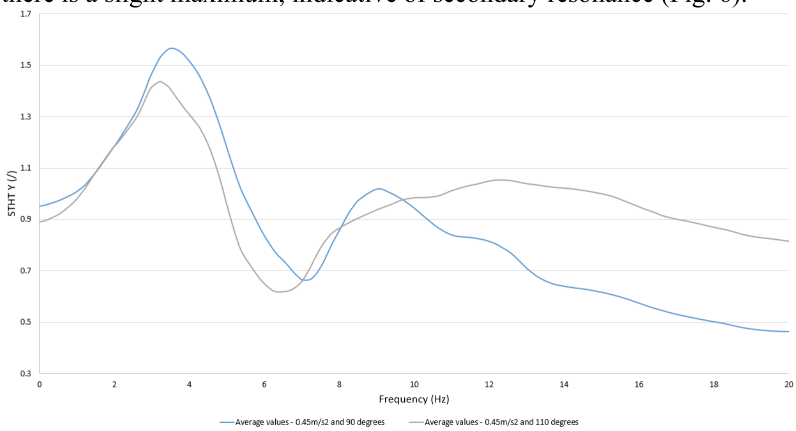

Fig. 6. Mean values of the STHT response in the vertical direction (excitation 0.45 m/s^2 r.m.s., angles of inclination of seat back 90° and 110°)

A resonant frequency of 2.98 Hz was observed under the influence of an excitation of 1.1 m/s² r.m.s. (seat back 90°), with a mean amplitude value of the STHT response at 1.74 (Fig. 7).

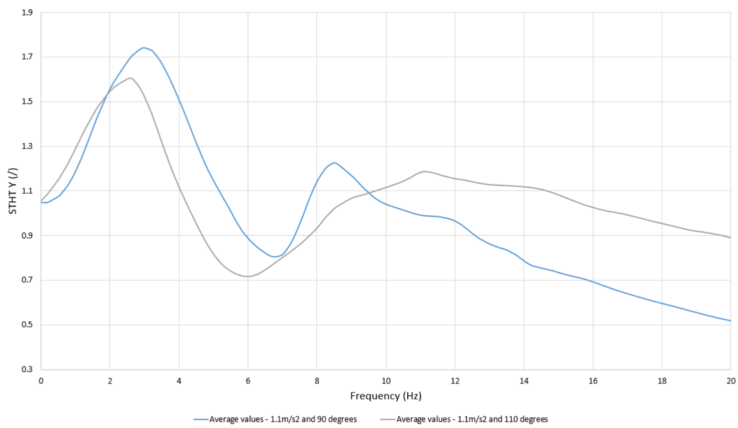

Fig. 7. Mean values of the STHT response in the vertical direction (excitation 1.1 m/s^2 r.m.s., angles of inclination of seat back 90° and 110°)

The lowest resonant frequency of 2.56 Hz and the highest mean amplitude value of the STHT response at 1.61 were observed under an excitation of 1.1 m/s² r.m.s. (seat back 110°) (Fig. 7).
Factor analysis was employed to determine the ranking of the influence of individual factors on the resonant frequency value of the STHT response. In the study, Analysis Of Variance (ANOVA) was applied. Five factors were analyzed, including height, weight, BMI, seated body height, and the age of the participants.

Table 1. Analysis of variance

Anthropometry	The mean value of the sum of squares	F ratio	Percentage share (%)
Height	0.12	1.16	3.71
Weight	0.23	6.3	19.55
BMI	0.32	17.68	37.18
Body height in a sitting position	0.27	15.54	29.4
Age	0.2	2.23	10.09

Analyses have shown that BMI is the most influential factor among the analyzed 20 male participants, with a contribution percentage of 37.18%. Another influential factor is body height in a sitting position with a share of 29.4%. Height and age have the least influence on body posture under the influence of vibrations.

3. CONCLUSION

The analysis of exposure to multi-axial vibrations (horizontal and vertical simultaneously) among male participants revealed an additional decrease in resonant frequencies of STHT responses in both observation directions. Resonant frequencies ranged from 2.85 Hz to 3.83 Hz for STHT response in the vertical direction, while for STHT response in the fore-and-aft direction, they ranged from 2.35 Hz to 2.97 Hz. The general conclusion is that ANOVA analysis of variance can aid in understanding the influence of individual factors on the function of the frequency response of STHT. This analysis showed that BMI has the greatest influence on the frequency response of a body exposed to multiaxial vibrations.

ACKNOWLEDGMENT

This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through Grant TR35041 and 451-03-47/2023-01/200378. Also, this research is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No 952603. This article reflects only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

4. LITERATURE

[1] Nawayseh N. & Griffin M. J. (2004), "Tri-axial forces at the seat and backrest during whole-body vertical vibration", *Journal of Sound and Vibration*, 309–326.

[2] Rakheja S., Dong R. G., Patra S., Boileau P-É., Marcotte P. & Warren C. (2010), "Biodynamics of the human body under whole-body vibration: Synthesis of the reported data", *International Journal of Industrial Ergonomics*, No. 40, 710–732.

[3] Toward MGRT. & Griffin MJ. (2009), "Apparent mass of the human body in the vertical vibration: Effect of seat backrest", *Journal of Sound and Vibration*, 327(3-5), 657-669, 2009.

[4] Gan Z., Hillis A.J., Darling J. (2013), "Development of a biodynamic model of a seated Human body exposed to low frequency whole-body Vibration", *11th International Conference on Vibration Problems*, Lisbon, Portugal.

[5] Demic M. & Lukic J. (2009), "Investigation of the transmission of fore and aft vibration through the human body", *Applied Ergonomics*, No. 40, 622-629.

[6] Saveljic I., Saveljic S. M. & Filipovic N. (2021) "Numerical analysis of vibration effects on the lumbar spine", *20th International Symposium Infoteh-Jahorina*, Bosnia and Herzegovina.

[7] ISO 2631-1 (1997), "Evaluation of Human Exposure to Whole-Body Vibration. Part 1: General Requirements", International Organization for Standardization Geneva.