The Effects of Posture on Suspension Seat Transmissibility during Exposure to Vertical Whole-Body Vibration

S. Aisyah Adam¹, N. A. Abdul Jalil*, K. A. Md Razali¹, Y. G. Ng¹
¹Sound and Vibration Research Group, Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), 43400 UPM Serdang, Selangor, Malaysia

*Corresponding author: nawalaswan@upm.edu.my

Abstract. Suspension seat is used in the off-road condition to attenuate excessive vibration exposed to the human body. The efficiency of a seat reducing vibration not only depends on the dynamic characteristics of the seat, but the dynamic characteristics of human body and the characteristics of the input vibration as well. Tractor drivers adopted different postures during their farm work activities, which may influence the dynamic characteristics of the human body. However, the influenced of the driver’s posture on suspension seat transmissibility has received less systematic attention. Thus, this study is carried out with the objective to investigate the effect of different postures on seat transmissibility when seated on a suspension seat. Three male subjects were exposed to random vibration at 2.0 m/s² r.m.s with frequency ranging from 1-20 Hz, while seated on a vibration simulator for 60 seconds. The subjects adopted four seating postures: (i) relaxed, (ii) slouched, (iii) tensed and (iv) with backrest support. The study found that relaxed and slouched postures have a resonance frequency at 2.0 Hz. However, as the posture changed to backrest support, the resonance frequency of the seat transmissibility slightly increased by 0.25 Hz. This study suggested that changing the postures caused changes in the dynamics of human body, and thus affected the suspension seat transmissibility. It is concluded that, non-linearity in suspension seat transmissibility is influenced by the changes of body postures.

1. Introduction
The characteristics of the vibrations to which the human body is exposed differ widely between environments. Off-road vehicles including agricultural tractors, construction trucks and heavy machineries operate on the uneven surface, and thus exposed to higher levels of whole-body vibration (WBV). When agricultural vehicles moving on the uneven ground's surface, the whole of its framework is exposed to complex oscillatory motion, which is caused by the vibration from the engine, and the interaction with the uneven terrain on the ground’s surface [1]. Intense low frequency of vibration (0.5 to 80 Hz) mainly induced by the unevenness of the ground surface may reduce levels of comfort and increase the potential of musculoskeletal disorders (MSDs), particularly low back pain (LBP) [2-4]. It is evident that higher vibration magnitude is transmitted to the human body on off-road condition as compared to the on-road condition [5-7].

Primary contact of the vertical WBV transmitted to the human body is through the seat. Hence, suspension seat is introduced to attenuate vibration transmitted to the human body. The efficiency of a seat in attenuating the vibration depends on: (i) seat transmissibility, (ii) the sensitivity of the human body to the vibration, and (iii) the input vibration at the seat base. Seat transmissibility can be defined as the ratio of output vibration (on the seat surface) to the input vibration (on the seat base), and often
be used to quantify the seat performance. There are three different types of suspension seat commonly use in the field, which are: passive, semi-active and active. A recent study found that active suspension system with fuzzy logic controller could improve the suspension seat performance [8]. Even though various studies demonstrated the reduction of the vibration transmitted from optimising the suspension seat, the influence of human body should not be ignored.

Human body formed a coupled system with suspension seat and affect the efficiency of a seat [9]. Drivers adopted different postures during farm work activities, and it is highly dependent on the task they are doing. When the body moves from its original posture, the weight is shifted, and thus may prevented from the suspension seat to work properly. Nevertheless, less is known about the effect of posture on suspension seat transmissibility. Thus, this study was carried out with the objective to study the effect of different postures on vertical suspension seat transmissibility. It is hypothesised that the suspension seat transmissibility is influenced by the posture of human body.

2. Methods and Procedures

2.1. Experimental Setup
Suspension seat use in this study is from agricultural tractor that is commonly used in Malaysia. The cushion is removed, and the suspension system is attached to a rigid seat. Then, the seat is secured on top of the shaker. Vibration analysis of the structure was done prior to the experiment with SOLIDWORKS Simulation 2017.

Shaker was used to generate vibration in the vertical direction (z-axis). Random vibration was generated with the frequency range of 1 to 20 Hz at 2.0 m/s² of vibration magnitude. Vibration in the vertical direction was measured using single-axial integrated circuit piezo-electric (IEPE) accelerometers (B&K type 4514) with 100 mV/g sensitivity. The accelerometers were attached on top of the shaker (seat base) and on the suspension seat. Both of the accelerometers were calibrated prior to the experiment. The signals were acquired using data acquisition (NI-9234) and the signal processing was analysed in the MATLAB 2018. The waveform were low-pass filtered at 50 Hz via anti-aliasing filter.

The schematic diagram of the experimental setup is shown in Figure 1.

![Figure 1. Schematic diagram of the experimental setup](image)
2.2. Subjects and Postures

Three healthy male subjects participated in the study. Healthy here means the subject did not have background of accident, incident or disease that cause low back pain and other musculoskeletal disorders. Written consent form was collected prior to the experiment. Ethical approval was obtained from the Ethics Committee for Research involving Human Subjects of Universiti Putra Malaysia (JKEUPM). The physical characteristics of the subjects are summarised in Table 1.

| Table 1. Subjects’ physical characteristics. |
|--------------------------------------------|
| Age (years) | 27.3 | 5.43 | 23 | 35 |
| Weight (kg) | 62.0 | 5.9 | 55.8 | 70.0 |
| Height (m) | 1.68 | 0.02 | 1.65 | 1.72 |

The subjects adopted four seating postures: (i) relaxed, (ii) slouched, (iii) tensed and (iv) with backrest support. They are instructed to put their hands on their laps, and rested their feet on a footrest that was attached to the shaker platform. Subjects wore a loose fitting lap belt for safety. The subjects were asked to maintain the desired posture for 60 seconds during exposure to vertical vibration. The sitting conditions were shown in Figure 2.

2.3. Analysis

Transfer functions between the acceleration at the base of the seat and the acceleration on the suspension seat were calculated using cross spectral density (CSD) method with a 0.25 Hz of frequency resolution. The seat transmissibility is determined from the ratio of the input and output acceleration of the CSD to the power spectral density (PSD) of input acceleration. The CSD method is used to minimise the effect of noise, and can be expressed as:

$$\frac{H(f)}{G_{ii}(f)} = \frac{G_{io}(f)}{G_{ii}(f)}$$

where $H(f)$ is the transfer function by CSD method, $G_{io}(f)$ is the cross spectrum of the input (seat base) and output (suspension seat) and $G_{ii}(f)$ is the power spectrum of input acceleration.

Using CSD method gives advantage in a way that it is a complex function, and provides both modulus and phase of the transfer function, as shown in Eq. 2 and Eq.3:
Modulus = \sqrt{(R(H(f)))^2 + (I(H(f)))^2} \tag{2}

Phase = \tan^{-1} \left[ \frac{I(H(f))}{R(H(f))} \right] \tag{3}

where $R(H(f))$ is the real part of the transfer function, and $I(H(f))$ is the imaginary part of transfer function.

In order to estimate how the output acceleration are related to input functions, the coherency may be determined such as:

$$Coherency \gamma_{ii}^2(f) = \frac{|G_{ii}(f)|^2}{G_{ii}(f)G_{oo}(f)} \tag{4}$$

where $G_{oo}(f)$ is the PSD of output acceleration.

The principal resonance frequency was defined as the frequency at which resulted to the highest peak of the suspension seat transmissibility. It is expected that the principal resonance frequency is at the range of 1-20 Hz.

3. Results and Discussion

3.1. Effect of subject posture on suspension seat transmissibility

Seat transmissibility of seated subjects for all postures are shown in Figure 3-6. All the subjects showed three peak with the highest peak is around 1-3 Hz for all postures. This is consistent with previous study done by Qiu where the author found three peaks with a primary peak in the frequency range below 6 Hz [10]. All the data showed high coherency (above 0.8), which suggested the system is linearly correlated. The median data for all the postures adopted in the study is shown in Figure 7.

Similar resonance frequency is observed during relaxed and slouched posture, which is at 2.0 Hz. However, slightly higher peak of seat transmissibility was found for relax posture as compared to slouched posture (from 1.245 to 1.324). When the posture is changing from slouched to tensed, the resonance frequency increased by 0.25 Hz (from 2.0 Hz to 2.25 Hz).

Previous studies reported the resonance frequency of apparent mass of a seated human body is higher in tensed posture as compared to relaxed posture [11]. Changes in muscle tension resulting from the changes of upper-body posture would influence the magnitude of the muscular activity in response to vibration [12]. Tensed posture caused the pressure under the ischial tuberosity to the seat increased, and thus, resulted to slightly increases in the resonance frequency of the seat transmissibility.
Figure 3: Seat transmissibility, phase and coherency for relaxed posture.

Figure 4: Seat transmissibility, phase and coherency for slouched posture.
Figure 5: Seat transmissibility, phase and coherency for tensed posture.

Figure 6: Seat transmissibility, phase and coherency for backrest posture.
3.2. Effect of backrest
Adding a rigid backrest support slightly increased the resonance frequency of seat transmissibility, as compared to different postures without backrest support (relaxed, slouched and tensed). Backrest may introduce additional vibration to the seated body. Note that in this study, a rigid backrest support is used, hence there is no attenuation of vibration from the backrest support to the seat. However, recent study found that reclined backrest support may increase transmission to body resonance as compared to upright backrest support [13]. Contact with the backrest support could constraint the movement of upper body parts, and thus alters the dynamic response of human body [14]. Consequently, changes in the dynamic response influenced the suspension seat transmissibility.

4. Conclusions
The results showed different postures slightly affect the resonance frequencies of suspension seat transmissibility. Changes in the resonance frequency is apparent when the body postures changes from relaxed and slouched to tensed. This is due to changes of stiffness and damping exhibits by the body, which alters the pressure under the ischial tuberosities to the seat. In this study, it is proved that the influence of human body should not be ignored in optimising the performance of suspension seat.

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