Postprint: Finite Element Study of Human Head Vibration Response in Upright Sitting Posture

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Abstract

To investigate the response characteristics of different head regions under whole-body vibration environments, a full-human finite element model with detailed skeletal and muscular soft tissues was developed. The modal method and random response method were employed to calculate the vertical first-order resonance frequencies and head-to-seat vibration transmissibility for both segmental models and seated occupant models, and the model was tuned and validated through comparisons with experimental and simulation studies. The study found that: under vertical vibration excitation, the upright seated human body exhibits a pronounced resonance phenomenon near 5.7 Hz. The vertical (Z-direction) response of the head reaches its maximum in the sagittal plane at the occipital region; the head-to-seat transmissibility at the occiput is 10% greater than at the crown and 23% greater than at the forehead, while in the coronal plane, the Z-direction responses at different head positions are nearly identical; the maximum anterior-posterior (X-direction) response occurs at the crown, with response peaks in both the sagittal and coronal planes being symmetric about this point, and the X-direction response variation across different positions reaches 119%. Through vertical modal shape analysis, it was discovered that the seated human body exhibits not only vertical and anterior-posterior displacements but also head rotation, resulting in complex coupled vibrations of the head within the sagittal plane, which gives rise to the aforementioned vibration distribution patterns.

Full Text

Finite Element Method Study on the Vibration Response of the Human Head in an Upright Sitting Position

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Abstract: This study investigates the response behavior of the human head under whole-body vibration using finite element analysis. A detailed seated human finite element model incorporating skeletal and muscular soft tissues was developed based on CT scan data of a 179 cm, 80 kg individual. The model was processed using ANSA software and analyzed in ABAQUS. Modal analysis was employed to calculate the resonant frequencies of each body segment, while the random response method was used to compute seat-to-head transmissibility. The model was tuned and validated against experimental and simulation data from literature. Results demonstrate that an upright sitting human exhibits a pronounced resonance phenomenon around 5.7 Hz under vertical vibration excitation. The vertical (Z-direction) seat-to-head transmissibility at the crown is 10% larger than at the forehead, while the Z-directional response in the sagittal plane shows maximum values in the posterior occipital region, which are 23% greater than those at the crown. The maximum difference in X-directional response across different head positions reaches 119%. Modal vibration analysis reveals that the seated human body experiences not only vertical and fore-and-aft displacements but also rotational movements, leading to complex coupled vibration of the head in the sagittal plane. These findings provide theoretical reference and basis for vibration testing, model development, and vibration comfort evaluation for vehicle occupants.

Keywords: upright seated human body; finite element method; vibration response; modal analysis; seat-to-head transmissibility; random response analysis

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1. Research Methods

1.1 Creation of the Upright Seated Human Finite Element Model

The geometric model was reconstructed from CT scans of a male subject (179 cm height, 80 kg weight). The model includes detailed representations of skeletal structures and muscular soft tissues. ANSA software was utilized for model preprocessing, including geometry cleanup, mesh generation, and material property assignment. The final finite element model comprises solid and shell elements as shown in [FIGURE:1], with C3D4 tetrahedral elements used for solid tissues and M3D4 membrane elements for soft tissues. The mesh was refined in critical regions, with element sizes ranging from 1–2 mm for detailed structures to 20–40 mm for larger body segments, achieving a total of 2,463,949 elements in the final model.

1.2 Material Properties

Material properties were assigned based on established literature values for human tissues. Bone structures were modeled as linear elastic materials, while soft tissues were represented using hyperelastic or viscoelastic models as appropriate. The material parameters are summarized in , including density, Young' s modulus, Poisson' s ratio, and damping coefficients for each tissue type.

1.3 Random Response Analysis

Random response analysis was performed in ABAQUS to compute vibration transmissibility across a frequency range of 0–20 Hz. A vertical acceleration input of 0.05 m/s^2 was applied at the seat base. The seat-to-head transmissibility $T_i(f)$ was calculated as the ratio of head response to seat input in each direction:

$$T_i(f) = \frac{a_{\text{head},i}(f)}{a_{\text{seat},i}(f)}$$

where $i = X, Y, Z$ represents the three translational axes and f is frequency in Hz. The analysis accounted for the full coupling between different vibration modes and directions.

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2. Research Results

2.1 Mesh Convergence Analysis

A mesh convergence study was conducted comparing models with 2,463,949 elements and 624,763 elements. The difference in seat-to-head transmissibility results between these mesh densities was less than 5%, confirming that the finer mesh provided converged solutions [FIGURE:2].

2.2 Validation of the Seated Human Model

The vertical seat-to-head transmissibility at the forehead was compared with published experimental and simulation data under identical conditions. The predicted transmissibility curve shows good agreement with reference data, particularly around the primary resonance frequency, validating the model' s accuracy [FIGURE:3].

2.3 Head-Seat Vibration Transmissibility

The vertical (Z-direction) seat-to-head transmissibility exhibits a primary resonance peak at approximately 5.7 Hz [FIGURE:4], which corresponds to the first-order vertical resonance of the spine. This frequency aligns with reported values for L3-L4, L3-L5, L1-L5, T12-pelvis, T1-pelvis, and C1-L5 segments from literature . The maximum transmissibility occurs at the crown of the head, with values 10% higher than at the forehead. In the sagittal plane, the Z-directional response distribution shows peak values in the posterior occipital region, which are 23% greater than those at the crown.

The fore-aft (X-direction) transmissibility also shows significant amplification, with maximum differences of 119% between different head positions

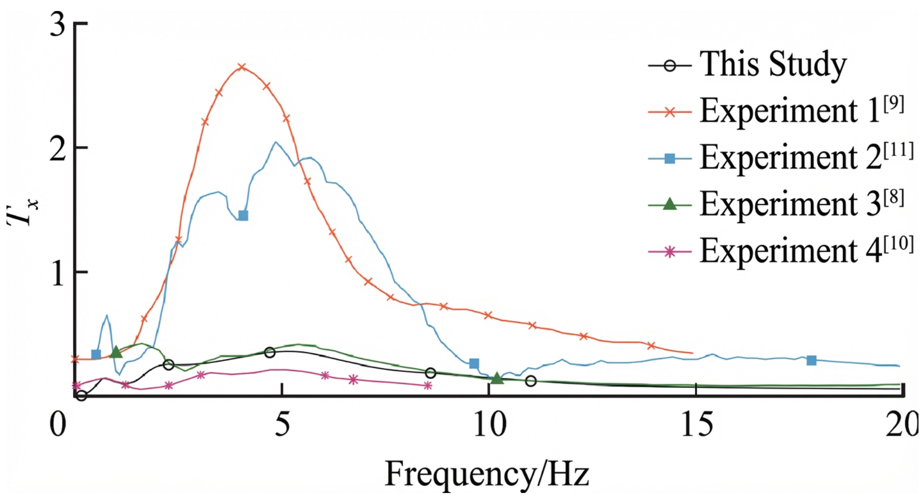

Figure 1: Figure 5

. The response distribution in the coronal plane is relatively uniform, while the sagittal plane response is symmetric about the vertical axis.

Modal analysis reveals that at 5.7 Hz, the seated human body exhibits coupled vibration modes involving vertical displacement, fore-aft rocking, and rotational motion about the hip joint [FIGURE:6]. This complex coupling explains the observed vibration distribution patterns in the head.

3. Discussion

The predicted 5.7 Hz resonance frequency is consistent with values reported by RAHMATALLA and FRITZ (5-6 Hz range) and other studies (4-6 Hz range) . The 119% variation in X-directional response across head positions is comparable to the 110-120% range reported in literature. The model successfully captures the spatial variation in vibration response, with posterior occipital regions showing higher Z-directional acceleration than the crown, consistent with experimental observations by PADDAN and GRIFFIN.

The complex vibration coupling revealed by modal analysis—combining vertical, fore-aft, and rotational motions—highlights the importance of multi-degree-of-freedom modeling for accurate prediction of head vibration response. This coupling effect is particularly significant in the sagittal plane and contributes to the non-uniform distribution of vibration across the head.

The validated model provides a reliable tool for evaluating vibration comfort and for optimizing seat design to reduce head vibration exposure in vehicle occupants. Future work should consider individual anthropometric variations and muscle activation effects to further enhance model fidelity.

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