RESEARCH ON THE EFFECT OF HEADREST SUPPORT ON RIDING COMFORT

NGHIÊN CỨU ẢNH HƯỞNG CỦA TỰA ĐẦU ĐẾN SỰ THOẢI MÁI KHI LÁI XE

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ABSTRACT

Riding comfort has become an essential consideration in modern vehicle design. It directly influences user satisfaction, health, and safety during transportation. This research investigates the impact of headrest support on both passenger and driver comfort under various riding conditions. Simulation results show that, although the presence of headrest support may lead to a slightly less stable posture, it significantly reduces the amplitude of head displacement, which in turn helps to decrease neck tension and fatigue.

Keywords: *Headrest support; Riding comfort; Simulation.*

TÓM TẮT

Sự thoải mái khi lái xe đã trở thành một yếu tố quan trọng trong việc thiết kế xe hiện đại. Mức độ thoải mái ảnh hưởng trực tiếp đến sự hài lòng, sức khỏe và sự an toàn của người dùng trong quá trình vận chuyển. Nghiên cứu này phân tích tác động của tựa đầu đối với sự thoải mái của cả hành khách và người lái xe trong nhiều điều kiện lái xe khác nhau. Kết quả mô phỏng cho thấy, khi có tựa đầu tư thế ngồi kém ổn định hơn một chút, nhưng nó làm giảm đáng kể biên độ dịch chuyển đầu, từ đó giúp giảm căng thẳng và mệt mỏi ở cổ.

Từ khóa: *Tựa đầu; Sự thoải mái khi lái xe; Mô phỏng.*

1. INTRODUCTION

In the vehicle manufacturing, riding comfort is the most important factors to be considered in the design stage. As vehicles become more advanced, users expect not only performance and safety but also a high degree of comfort. Among the various components that contribute to this, the seating system, including the headrest support, plays a crucial role in ensuring both physical well-being and driving satisfaction.

Riding comfort significantly affects user satisfaction, long-term health, and overall driving experience. One of the most sensitive areas affected during driving is the neck and upper spine region, especially under conditions of prolonged travel, sudden acceleration or deceleration, and exposure to road vibrations.

Over the past two decades, neck injuries have become a major concern in traffic safety. Despite this, relatively little effort has been devoted to the optimization of car seat and headrest design in comparison to other vehicle safety features such as airbags or seatbelts.

Several research studies have shown that a well-designed headrest encourages a relaxed, neutral posture by supporting the cervical spine, thereby reducing muscle tension and fatigue. This support helps alleviate discomfort and prevents neck pain, making both short commutes and long-distance travel more comfortable for drivers and passengers alike.

While the benefits of headrest support have been recognized qualitatively, quantitative analysis of its impact on human biomechanics during real or simulated driving conditions remains limited. This research aims to evaluate the effect of headrest support on riding comfort using a computational approach.

For the purpose of this study, an integrated human-vehicle model with seventeen degrees of freedom (DOFs) was developed to simulate and analyze the dynamic interaction between the seated human body and the vehicle environment.

2. MODELING CONSTRUCTION

2.1. Seated human model with headrest support

In order to study on the effects of seated human subjects, the nine-DOF biomechanical model [1] is modified by adding a headrest part as shown in Figure 1(a). Practically, the mechanical properties of human's head are usually larger than the mechanical properties of human's back. However, how much different between them need to do experiment and study deeply in biomechanical of human subjects. For reference, mechanical properties of headrest support and human's head are assumed similar to mechanical properties of the backrest support and human's back, respectively. Geometrical parameters of seated human model with headrest support are listed in Table 1. A free body diagram is shown in Figure 1(b). The system EOMs are modified as follows:

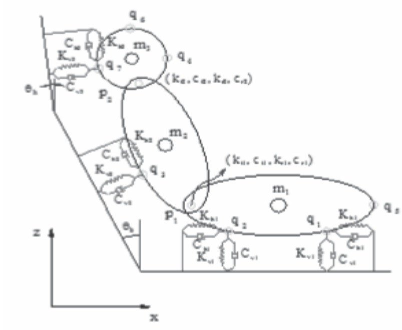
$$\begin{pmatrix} m_1\ddot{x}_1 \\ m_1\ddot{z}_1 \\ I_1\ddot{\theta}_1 \end{pmatrix} = \begin{pmatrix} f_{x12} + f_{x1q1} + f_{x1q2} \\ f_{z12} + f_{z1q1} + f_{z1q2} \\ T_1 \end{pmatrix};$$

$$\begin{pmatrix} m_2\ddot{x}_2 \\ m_2\ddot{z}_2 \\ I_2\ddot{\theta}_2 \end{pmatrix} = \begin{pmatrix} -f_{x12} + f_{x23} + f_{x2q3} \\ -f_{z12} + f_{z23} + f_{z2q3} \\ T_2 \end{pmatrix};$$

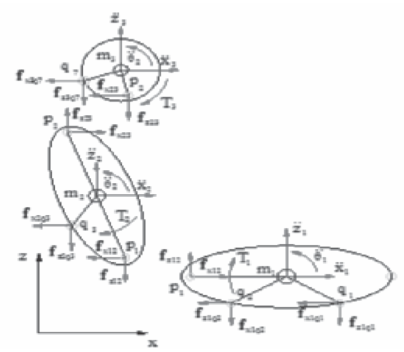
$$\begin{pmatrix} m_3\ddot{x}_3 \\ m_3\ddot{z}_3 \\ I_3\ddot{\theta}_3 \end{pmatrix} = \begin{pmatrix} -f_{x23} + f_{x3q7} \\ -f_{z23} + f_{z3q7} \\ T_3 \end{pmatrix} \quad (1)$$

Table 1. Biomechanical parameters of seated human model with headrest support [1]

Biomechanical parameters						Geometrical parameters			
Mass (kg) Inertia (kg.m²)		Damping (Ns/m)		Stiffness (N/m)		Length (m)		Angle (degree)	
m_1	15.30	c_{v1}	29.4	k_{v1}	72000.0	$l_{1p1} = 0.213$	$l_{2q3} = 0.106$	$\alpha_{11} = -72.5$	$\alpha_{01} = -27.4$
m_2	36.00	c_{h1}	447.0	k_{h1}	46300.0	$l_{2p1} = 0.204$	$l_{3q4} = 0.111$	$\alpha_{12} = -134.7$	$\alpha_{02} = -54.8$
m_3	5.50	c_{v2}	0.4	k_{v2}	2300.0	$l_{3p2} = 0.131$	$l_{0q1} = 0.270$	$\alpha_{23} = -48.7$	$\alpha_{03} = 140.3$
I_1	0.90	c_{h2}	446.0	k_{h2}	20200.0	$l_{1q1} = 0.114$	$l_{0q1} = 0.152$	$\alpha_{34} = 66.8$	$\theta_b = 21.0$
I_2	1.10	c_{t1}	380.6	k_{t1}	17200.0	$l_{1q2} = 0.167$	$l_{0q1} = 0.156$	$\alpha_{37} = -66.8$	$\alpha_{07} = 117.1$
I_3	0.03	c_{t2}	182.1	k_{t2}	25000.0	$l_{3p7} = 0.111$	$l_{0q7} = 0.527$		
		c_{r1}	2576.5 (Ns/rad)	k_{r1}	0.0 (N/rad)				
		c_{r2}	1.3 (Ns/rad)	k_{r2}	100.0 (N/rad)				



a) Model



b) Free body diagram

Figure 1. Seated human model with headrest support

2.2. Integrated human-vehicle model

In this study, the motions of each part of seated human model are considered in plane motion (translational motions in x and z directions, rotational motion respect to y-axis). So, the pitch motion of the vehicle also is considered as a role of input excitation to seated human model. Accordingly, an integrated human-vehicle system can be achieved by deleting the driver mass from 3-D vehicle model and substituting the seated human model. Assume that, the vehicle body and the vehicle seat are interconnected by a system of parallel linear springs and dampers with corresponding stiffness coefficient k_d and damping coefficient c_d. For this reason, the translational motion in vertical direction and the rotational motion respect to y-axis of the vehicle seat are considered as the translational motion in vertical direction of vehicle-seat position on vehicle body and rotational motion of vehicle body respect to y-axis.

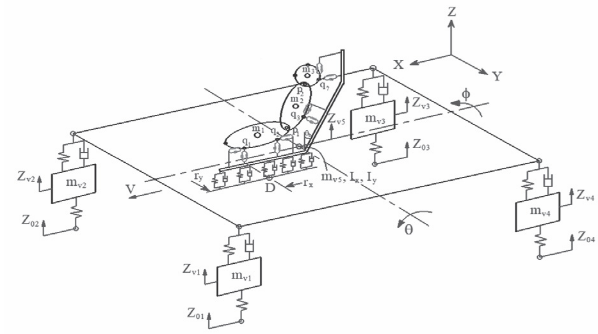


Figure 2. Schematic of integrated human-vehicle model

The integrated human-vehicle model is shown in Figure 2. Based on the system of EOMs of the nine-DOF multi-body model with headrest support and the system of EOMs of the 3-D vehicle model [2], the EOMs of a completely integrated human-vehicle model can be expressed by the following matrix form:

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{F} \qquad (2)$$

The terms M, C and K in Equation (2) are the 17×17 mass, damping and stiffness matrices of the integrated human-vehicle model, respectively; and $\ddot{\mathbf{X}}$, $\dot{\mathbf{X}}$, and X are the acceleration, velocity and displacement vectors of the system; F is the force input due to road excitation.

2.3. Road Profiles

In this part of the study the different road classes, prescribed by ISO 2631 [3] and defined by the road roughness coefficients G_r, as listed in Table 2, are considered as the inputs for the vehicle wheels. Simulations of the integrated human-vehicle model in different random road profiles are also conducted, followed by an evaluation of the riding quality level for each profile.

Table 2. Road-roughness coefficients G_r (m^2/cycle/m) classified by ISO 2631 (1997) [3]

Road Class	A Very good	B Good	C Average	D Poor	E Very poor	F	G
Gr (10^{-6})	4	16	64	256	1024	4096	16384

The disturbance to the wheels on the front axles can be represented by two white-noise signals ($w_1(t)$ for left side and $w_2(t)$ for right side) passing through the first-order filter G(s):

$$G(s) = \frac{(2\pi G_r V)^{1/2}}{s + \omega_0} \quad (3)$$

Where: G_r is the road-roughness coefficient; V is vehicle velocity;

$\omega_0 = 2\pi v_0 V$ (v_0 is a spatial cut-off frequency between 0.001 and 0.02 cycle/m and used to limit the displacement to be finite at vanishingly small spectral frequencies).

Moreover, it is reasonable to consider the excitation at the rear wheels as a pure time delay, t_0 of those at the front wheels, and t_0 the ratio of wheelbase (L) to vehicle velocity ($t_0 = L/V$).

Again, a class C road surface is selected and the velocity is setting at 30m/s.

3. SIMULATION RESULTS

In this part, to evaluate the effect of headrest support, the seat-to-head (STH) transmissibility with headrest support is compared to that without headrest support, as shown in Figure 3. The simulation results indicate a significant difference between the STH transmissibility profiles in the two cases. The resonant frequency with headrest support is observed at 3.0 Hz, which is notably lower than the 4.0 Hz resonant frequency recorded without headrest support. The head response magnitude at the resonant frequency with headrest support is 3.27, slightly higher than that in the case without headrest support, which is 3.09.

Furthermore, the simulation results show that the head response magnitude is reduced in the frequency range of 4-11 Hz, but increased at higher frequencies beyond this range. Accordingly, the presence of headrest support leads to a reduction in resonant frequency, an increase in head response magnitude at resonance, and demonstrates better vibration isolation performance within the 4-11 Hz range, particularly around 8 Hz.

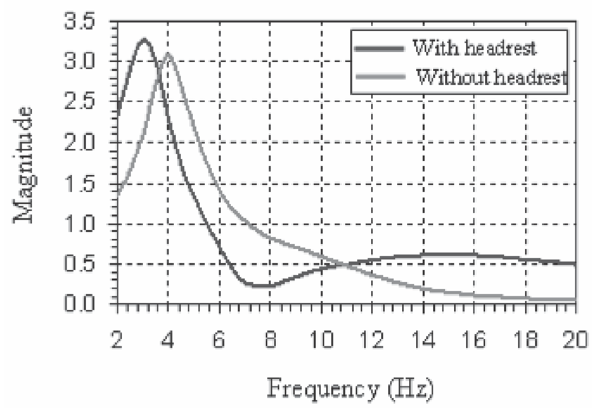
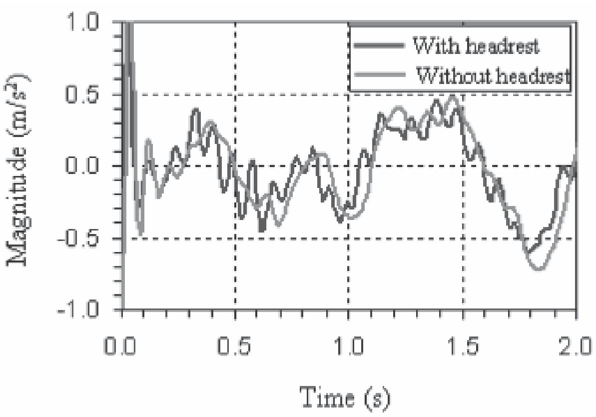


Figure 3. Comparison of seat to head transmissibility of human body with and without headrest support

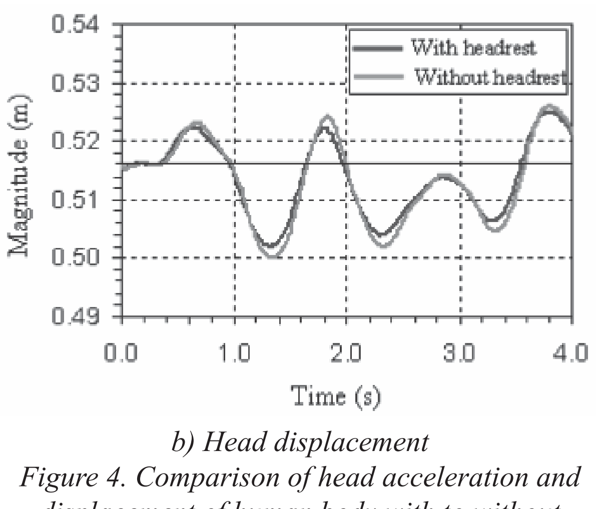
Figure 4 presents a comparison of head acceleration and head displacement of the human body with and without headrest support on a Class C road surface at a vehicle speed of 30 m/s. As shown in Figure 4(a), the head ☞

acceleration with headrest support oscillates at a lower frequency compared to the case without headrest support. This suggests that the presence of headrest support may result in a slightly less stable posture; however, as illustrated in Figure 4(b), the amplitude of head displacement is significantly reduced. This reduction in displacement helps to decrease tension and fatigue in the neck.

Overall, headrest support may play a crucial role in alleviating neck pain and enhancing driving comfort, particularly during long-duration trips.



a) Head acceleration



b) Head displacement

Figure 4. Comparison of head acceleration and displacement of human body with to without headrest support

4. CONCLUSIONS

In this research, the influence of the mechanical properties of headrest support on riding comfort was thoroughly evaluated. The study utilized an integrated human-vehicle dynamic model to investigate how headrest support affects both the stability and comfort of seated occupants under various riding conditions. The simulation results showed that, although the presence of headrest support may lead to a slightly less stable posture, it significantly reduces the amplitude of head displacement, which in turn helps to decrease tension and fatigue in the neck. ❖

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