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Dynamic characteristics of a compliant seat coupled with the human body and a manikin during the exposure to the whole-body vibration: effect of the polyurethane foam, the track position and the measurement location

XIAOLU ZHANG[1, 2], SEN LIN[1], XICHEN SONG[1], CHI LIU[2, 3], YI QIU[2, 3]*

[1] College of Mechanical & Energy Engineering, Beijing University of Technology, Beijing, China.
[2] Institute of Sound and Vibration Research, University of Southampton, United Kingdom.
[3] College of Energy Engineering, Zhejiang University, Hangzhou, China.

Transmissibility is used to assess dynamic responses of the occupant-seat system, and most studies have exclusively assessed the transmissibility from the floor to the cushion or the backrest surface with the human body. In this investigation, the vertical vibration transmitted from the floor to six specific locations both on the seat surface and the frame when the seat was fixed on three positions on the track was examined utilizing an SAE J826 manikin and 12 male adults (0.25 to 20 Hz) for a duration of 120 seconds at three vibration amplitudes. The transmissibility from the floor to the headrest frame, the cushion surface, the headrest surface, the seat back frame, and the seat back surface all exhibited a principal peak frequency within 4–5 Hz. With the exception of the cushion frame, the principal peak frequency and the peak transmissibility in transmissibilities to all positions decreased with increasing vibration amplitude, indicating the non-linearity within the occupant-seat system. It was also found modifying seat track positions minimally affected the seat transmissibility to either the surface or the frame of the seat. Polyurethane foam amplified vibration at peak frequency, simultaneously enhancing static sitting comfort and reducing the vertical vibration transmission above peak frequency.

Key words: *seat transmissibility, seat frame, seat track, manikin, headrest*

1. Introduction

Whole-body vibration is experienced by vehicle drivers and passengers during various transportations [12]. These vibrations can cause discomfort and health risks, including tiredness, fatigue, musculoskeletal disorders, cardiovascular diseases and neurological disorders [1], [22]. Therefore, understanding the vibrations transmitted through seats is necessary to minimize the riding discomfort and reduce the health risks.

The transmissibility of seats characterizes the degree to which the vibration amplitude is either amplified or attenuated as it is transmitted through the seat across different frequencies [8]. Typically, car seats loaded with a human body exhibit a principal vertical peak frequency approximately between 4 and 5 Hz, occasionally accompanied by a secondary peak frequency within the 9–12 Hz [1]. The seat transmissibility is dependent on the dynamic responses to the vibration of both the seat itself and the occupants [19]. Therefore, the seat transmissibility can be influenced by various factors that impact either the biodynamics or the seating dynamics. The biodynamic responses can be characterized by the apparent mass and the seating dynamics can be characterized by the dynamic stiffness, which is asso-

* Corresponding author: Yi Qiu, Institute of Sound and Vibration Research, University of Southampton, United Kingdom; College of Energy Engineering, Zhejiang University, Hangzhou, China. E-mail: YQiu@soton.ac.uk
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ciated with factors like the cushion thickness and the material property, etc [14], [15].

Seat transmissibility can be measured along any axis or at any point (e.g., on the cushion surface or seat back surface) and is assessed by comparing seat acceleration to that on the floor. Yao et al. [24] introduced an indirect approach to forecast seat transmissibility, where they derived the seat transmissibility of the cushion surface without subjecting individuals to vibration. This method combined measurements of the seat's dynamic stiffness alongside apparent mass to forecast the vertical seat transmissibility of the cushion surface.

The transmissibility of seats can be influenced by various factors, including the amplitude or spectrum of the vibration, the seat (e.g., the dynamic properties of the foam and seat structures) and the anthropometric parameters [3], [5], [25]. The majority of research on seat transmissibility has focused on the vertical transmissibility from the floor to the interface beneath the ischial tuberosities, presuming that the primary factor affecting the ride quality is the vertical transmissibility to the cushion [17]. Although the headrest may stabilize head movements and affect the seat-to-head-transmissibility, studies on vibration transmitted to car seat headrests or the frame are scarce. Furthermore, reports on vibration transmission to positions on a seat frame are also limited.

Car seats are frequently equipped with mechanisms to adjust the seat back inclination, the fore-and-aft position, the cushion angle or the seat height to accommodate occupants of varying sizes and provide flexibility for different sitting postures [26]. These adjustments are combined in modern seats by moving along the track mechanism in the seat system. Studies have reported the significant impact of cushion and seat back inclinations on the apparent mass [20] and a finite element (FE) model of the seated human body was established to calculate the biodynamic response of the lumbar spine with three inclined backrests under whole-body vibration [7]. However, to the best of the authors' knowledge, the impact for seat track positions on seat transmissibilities remains uncertain.

Vertical vibration transmitted to the cushion surface can be measured with a rigid mass, although significant differences between measurement with a rigid mass and with a human body are observed [19]. In comparison with the use of rigid masses for the test, the manikin may better represent the mass distribution supported on the cushion and the seat back [9]. The utilization of SAE manikin for seat transmissibility measurement is intriguing as it enables the comparison between transmissibility derived from manikin and that measured from human subjects and facilitates calibration of seat models.

The present study aimed to examine the vertical vibration transmission from the floor to the headrest, the cushion, and the backrest of a car seat, employing twelve participants and the SAE J826 manikin. Furthermore, measurements were taken to evaluate the vibration transmission to the seat frame, providing insight into the mechanisms underlying vibration propagation through the seat structure. The effect of seat track position on the vibration transmitted to either the surface or the frame was also investigated.

2. Materials and methods

In this investigation, a seat sourced from a car was employed, featuring a reclining seat back angled at approximately 25 degrees from the vertical plane, and with a cushion inclined at 6 degrees from the horizontal plane (Fig. 1). All three components (i.e., the headrest, the backrest and the cushion) of the seat were constructed with polyurethane foam covered by leather covers fixed to the metal frame. The seat was mounted onto the motion simulator, and the vibrations were measured at the floor, the cushion frame, headrest frame and backrest frame using four Entran EGCS-DO-10V accelerometers (sensitivity: 100 mV/g). Additionally, accelerations on the headrest, the backrest and the cushion surface were measured with triaxial SIT-pads embedded with Entran EGCS-DO-10V accelerometers within rubber molds, meeting ISO 10326-1 (1992) specifications (Fig. 1a, b). This design allowed the SIT-pads to effectively adapt to the elastic deformation between the human body and the foam, thereby reducing the noise and accurately measuring acceleration on soft parts. Signals were sampled at 512 samples per second.

The study enlisted twelve adult volunteers, whose anthropometric parameters are detailed in Table 1. Each participant underwent three 120-second vibration exposures characterized by random vertical vibration with amplitudes of 0.4, 0.8 and 1.2 m/s^2, featuring nearly constant-bandwidth acceleration spectra ranging from 0.25 to 20 Hz. These vibrations were experienced while seated at three different positions along the seat track: the rearmost and lowest, the foremost and highest, and at a mid-height and mid-fore-aft position, as shown in Fig. 2. Concurrently, electronic weighing scales were employed to measure the weight supported by both the feet and lower legs at each seat track position, enabling the calculation of the partici-

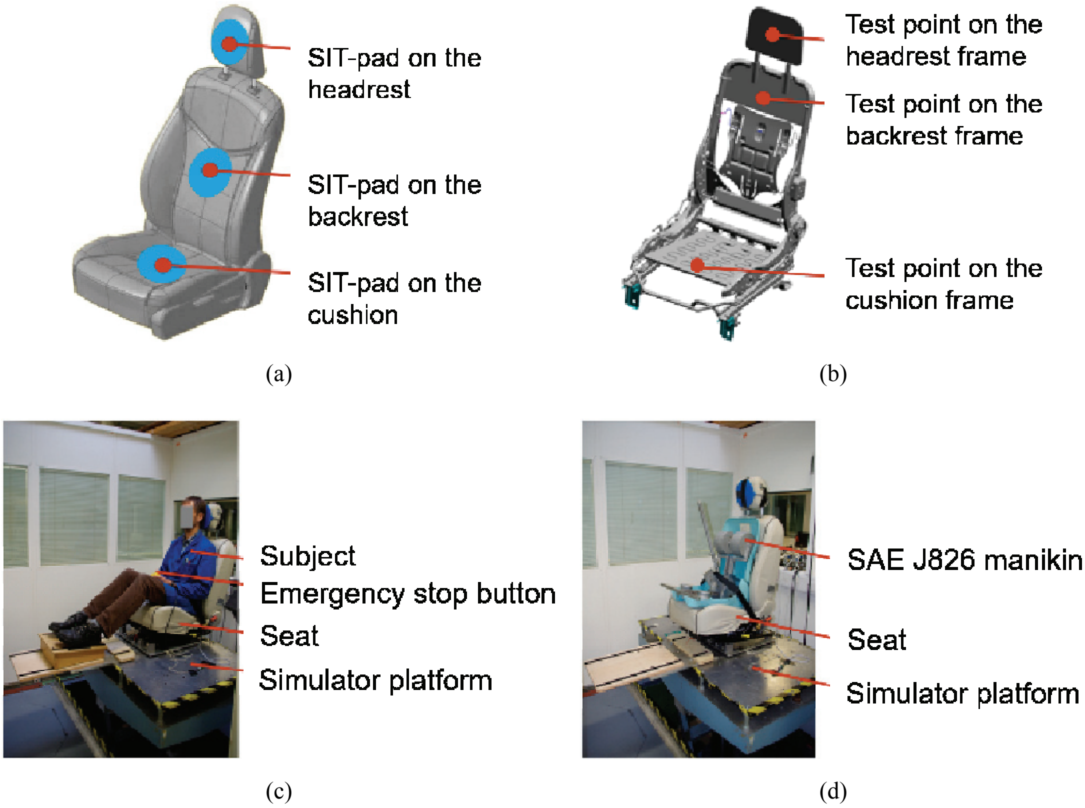

Fig. 1. The test schematic: (a) SIT-pad locations on the seat surface, (b) measurement locations on seat frames, (c) the seat with a participant seated, (d) the seat with an SAE J826 manikin seated

pant's sitting weight (i.e., total body weight minus the weight of the feet and lower legs), as shown in Table 1. For the manikin test, a winch was employed to recline the manikin until alignment was achieved with both the seat's central line and the H-point. The acceleration was measured at the following locations: (1) cushion surface, (2) cushion frame, (3) seat back surface, (4) seat back frame, (5) headrest surface, (6) headrest frame, as shown in Fig. 1.

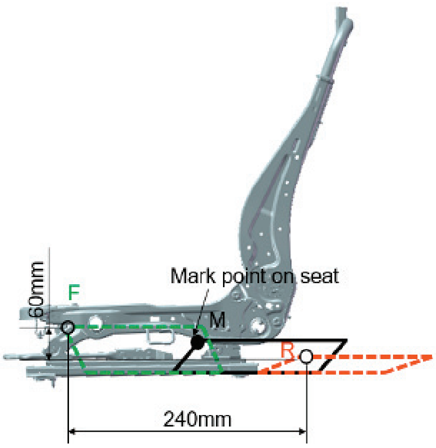

Fig. 2. Seat movement along the track.
F – the highest and foremost position, M – mid-mid position,
R – lowest and rearmost position

Before collecting data, participants were provided an informed consent forms detailing the objectives, procedures and potential risks of the experiment. The experiment was approved by the Human Experimentation Safety and Ethics Committee. All participants were informed about the nature of the experiments and their right to withdraw at any time without facing any consequences. The vibration conditions were controlled and checked in the preliminary study, with vibration dose values deemed acceptable based on BS6841 standards.

This study involved six seat transmissibilities:

1. TS_{cs} and TP_{cs}, defined as the transfer functions between the acceleration on the floor and the acceleration on cushion surface;
2. TS_{cf} and TP_{cf}, defined as the transfer functions between the acceleration on the floor and the acceleration on cushion frame;
3. TS_{bs} and TP_{bs}, defined as the transfer functions between the acceleration on the floor and the acceleration on seat back surface;
4. TS_{bf} and TP_{bf}, defined as the transfer functions between the acceleration on the floor and the acceleration on seat back frame;
5. TS_{hs} and TP_{hs}, defined as the transfer functions between the acceleration on the floor and the acceleration on headrest surface;

Table 1. The participants' anthropometric parameters

Participant number	Height [cm]	Weight [kg]	Age [years]	Sitting weight for each seat position [kg]		
				foremost	mid	rearmost
1	170.0	60.0	29.0	47.2	45.3	49.7
2	197.0	107.0	25.0	83.1	82.2	86.9
3	172.0	74.0	24.0	55.9	51.3	53.3
4	181.0	76.0	24.0	54.3	54.2	54.6
5	176.0	81.0	58.0	61.8	60.3	64.2
6	182.0	87.0	24.0	55.1	53.8	53.8
7	194.0	86.0	25.0	67.8	65.2	65.1
8	169.0	66.0	44.0	50.9	48.5	53.1
9	176.0	58.0	23.0	46.9	45.2	49.5
10	170.0	65.0	56.0	53.2	51.1	54.9
11	186.0	80.0	56.0	62.9	61.6	64.8
12	180.0	70.0	25.0	55.9	56.5	59.6
Average	179.4	75.7	35.4	57.9	56.3	59.1

6. TS_{hf} and TP_{hf}, defined as the transfer functions between the acceleration on the floor and the acceleration on headrest frame.

TS denotes the seat with an SAE J826 manikin seated, while *TP* denotes the seat with a participant seated.

3. Results

3.1. Seat transmissibility measured with a manikin

The TS_{cs} is depicted in Fig. 3a, exhibiting a principal peak frequency around 8 Hz and a secondary peak frequency at approximately 12 Hz. Both peak frequencies and transmissibilities decreased as vibration amplitude increased. As illustrated in Fig. 3b, the TS_{cf} showed a slight peak frequency around 8 Hz. Notably, transmissibility remained close to unity for frequencies below 20 Hz, aside from a minor peak around 8 Hz.

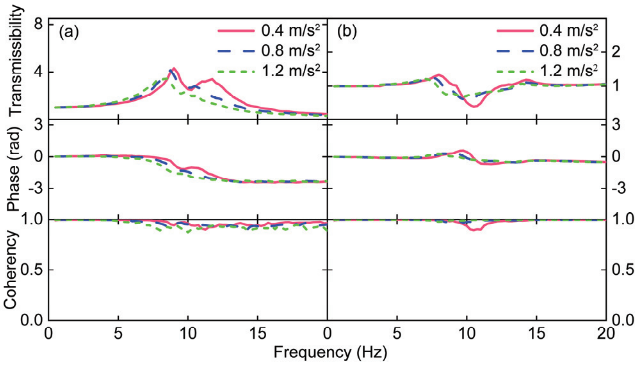

Fig. 3. The impact of vibration amplitudes on (a) TS_{cs} and (b) TS_{cf}

With increasing the vibration amplitude, similar to TS_{cs}, there was a decrease observed in both the principal peak frequency and transmissibility at around 8 Hz.

The TS_{bs} exhibited a principal peak frequency at approximately 9 Hz and an additional peak at around 12 Hz (Fig. 4a). As vibration amplitudes increased, there was a significant decrease observed in peak frequencies. The TS_{bf} is depicted in Fig. 4b. At frequencies below 20 Hz, the transmissibility was nearly unity, with the exception of two slight peak frequencies observed at approximately 8 Hz and 14 Hz. The principal peak frequency decreased with increasing vibration amplitude, paralleled by a reduction in peak transmissibility.

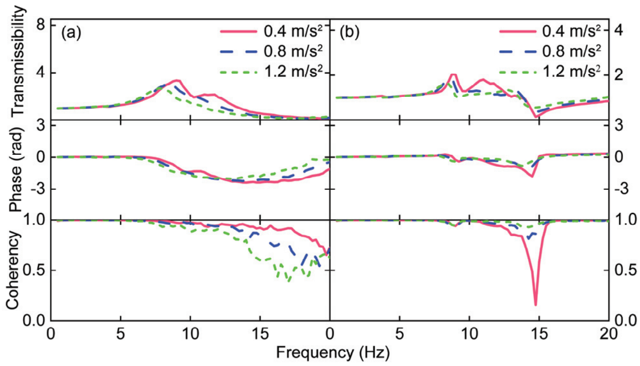

Fig. 4. The impact of vibration amplitudes on (a) TS_{bs} and (b) TS_{bf}

3.2. Seat transmissibility measured with the human body

3.2.1. Impact of vibration amplitudes on seat transmissibilities

When the seat was positioned at the mid-mid track location, the median transmissibilities from the floor to six locations with different vibration amplitudes were depicted in Figs. 5–7. Statistical analysis was conducted using SPSS (version 21) with non-parametric statistics. The statistical significance of difference in the seat transmissibilities with various seat conditions was calculated using the Friedman two-way analysis of variance method. The significance level, indicated by the *p*-value, was taken to indicate statistical significance when it was less than 0.01.

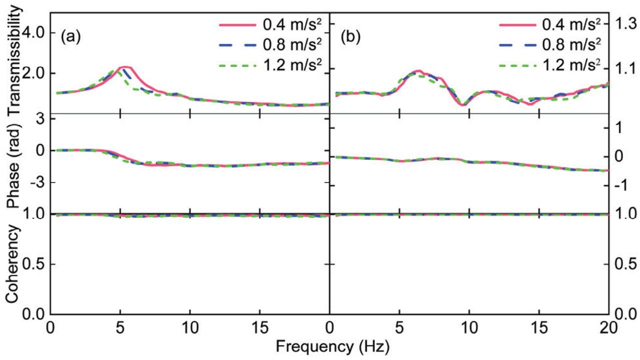

Fig. 5. The impact of vibration amplitudes on (a) TP_{cs} and (b) TP_{cf}

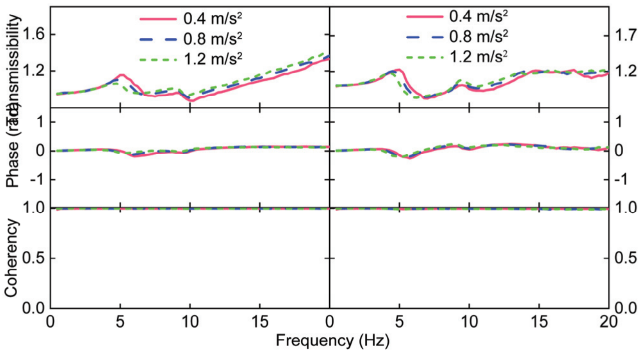

Fig. 6. The impact of vibration amplitudes on (a) TP_{bs} and (b) TP_{bf}

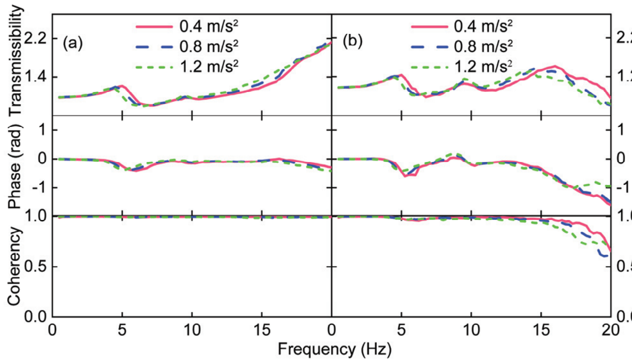

Fig. 7. The impact of vibration amplitudes on (a) TP_{hs} and (b) TP_{hf}

The median TP_{cs} revealed a principal peak frequency around 5 Hz (Fig. 5a). The principal peak frequency exhibited a decrease with increasing vibration amplitude ($p < 0.01$), accompanied by a corresponding decrease in peak transmissibility ($p < 0.01$). In Figure 5b, it was shown that, based on the TP_{cf} it can be observed that the transmissibility remained nearly unity below 20 Hz, except for a minor peak frequency within 4–5 Hz. The peak frequency, as well as the peak transmissibility, showed no statistically significant impact from vibration amplitudes ($p > 0.05$).

The TP_{bs} was illustrated in Fig. 6a and the peak frequencies were observed at approximately 4 to 5 Hz. Both the peak frequency around 4 to 5 Hz ($p < 0.01$) and the peak transmissibility decreased with increasing the vibration amplitude ($p < 0.01$). Peak frequencies could also be observed at approximately 4 Hz for the TP_{bf} (Fig. 6b). In the TP_{bf} and TP_{bs}, as vibration amplitude increases, both the peak frequency and the peak transmissibility demonstrate a marked decrease ($p < 0.01$).

In Figure 7a, a notable peak frequency at 5 Hz observed for the TP_{hs} was shown. Both peak frequen-

Table 2. The impact of vibration amplitudes on various seat transmissibilities at three seat track positions

	Transmissibility from floor to:	Seat track position		
		(F) Foremost	(M) Mid	(R) Rearmost
Principal peak frequency	Cushion surface	**	**	**
	Cushion frame	–	–	–
	Seat back surface	**	**	**
	Seat back frame	**	**	**
	Headrest surface	**	**	**
	Headrest frame	**	**	**
Peak transmissibility	Cushion surface	**	**	**
	Cushion frame	–	–	–
	Seat back surface	**	**	**
	Seat back frame	**	**	**
	Headrest surface	**	**	**
	Headrest frame	**	**	**

"**" denotes results with significant differences ($p < 0.01$), "–" denotes results with no significant differences.

cies ($p < 0.01$) and peak transmissibilities exhibited a decrease with the increase of vibration amplitude ($p < 0.01$). For both the TP_{hs} and TP_{hf}, it was observed that the principal peak frequency decreased as vibration amplitudes increased, accompanied by a decrease in peak transmissibility ($p < 0.01$).

3.2.2. Impact of seat track positions on seat transmissibilities

During the measurement, the inclination of the cushion varied from 3 to 10 degrees, and the inclination of the seat back ranged from 21 to 29 degrees, as the seat moved from the highest and foremost position to the lowest and rearmost position. Although the sitting weight and the sitting posture of each participant varied when the seat moved along the track at three positions, the Friedman two-way analysis of variance showed the variation in seat track positions had little impact on either peak frequencies ($p > 0.05$) or the peak transmissibilities ($p > 0.05$) of all the measured six transmissibilities, as depicted in Table 3. The median TP_{cs} and TP_{bs} were illustrated in Fig. 8 as two examples for the investigation of the effect of seat track positions on the measured transmissibilities.

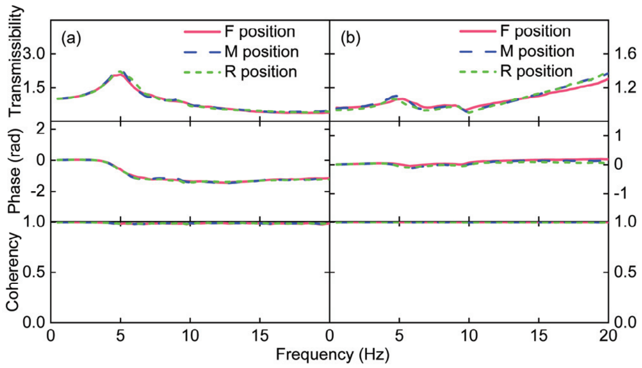

Fig. 8. The impact of seat track positions on (a) TP_{cs} and (b)TP_{bs} (vibration amplitude = 0.8 m/s^2)

3.3. Comparing seat transmissibilities between the measurement with the human body and the manikin

Distinct differences were displayed for the measured transmissibilities between with participants and with a manikin, and four examples were depicted in Fig. 9. When the seat was loaded with the manikin, TS_{cs} exhibited two peak frequencies at approximately 8 and 12 Hz, whereas with participants, the principal peak frequency was around 4 Hz (Fig. 9a). For the TS_{bs}, two peak frequencies at about 8 and 12 Hz were observed (Fig. 9b). Yet the transmissibilities displayed peak frequency at about 5 Hz when measured for participants. Similar differences were observed between TS_{cf} and TP_{cf}, and between TS_{bf} and TP_{bf}. Furthermore, there were slight variations in the coherencies associated with the transmissibilities between the human and the manikin, particularly regarding the transmissibilities from the floor to the seat back surface, where the coherency of the transmissibility with the manikin decreased with increasing frequency.

Table 3. The impact of seat track positions on seat transmissibilities at three vibration amplitudes

	Transmissibility from floor to:	Vibration amplitude		
		0.4 m/s^2	0.8 m/s^2	1.2 m/s^2
Principal peak frequency	Cushion surface	–	–	–
	Cushion frame	–	–	–
	Seat back surface	–	–	–
	Seat back frame	–	–	–
	Headrest surface	–	–	–
	Headrest frame	–	–	–
Peak transmissibility	Cushion surface	–	–	–
	Cushion frame	–	–	–
	Seat back surface	–	–	–
	Seat back frame	–	–	–
	Headrest surface	–	–	–
	Headrest frame	–	–	–

"**" denotes results with significant differences ($p < 0.01$), and "–" denotes results with no significant differences.

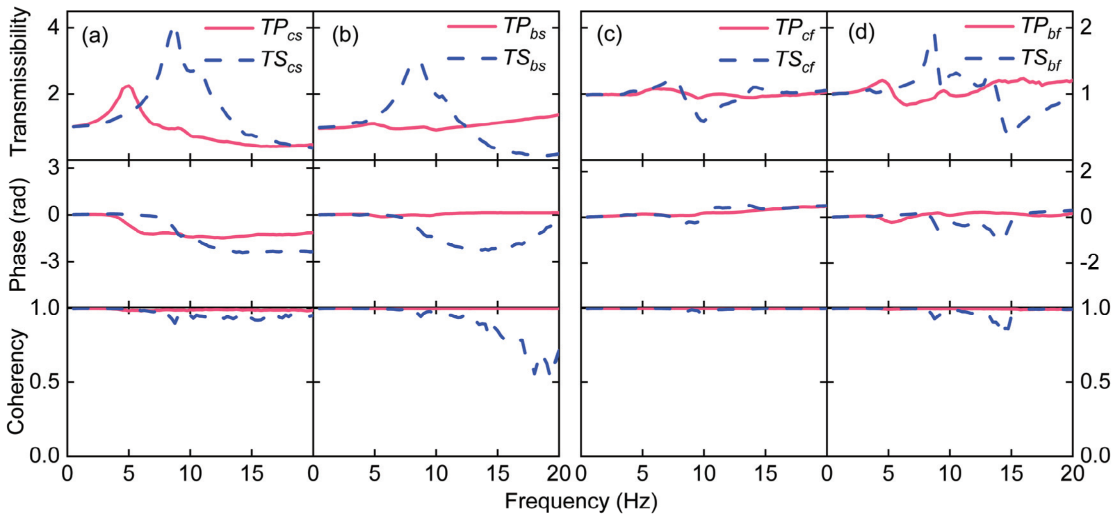

Fig. 9. Comparison between: (a) the TP_{cs} and the TS_{cs}, (b) the TP_{bs} and the TS_{bs}, (c) the TP_{cf} and TS_{cf}, (d) the TP_{bf} and the TS_{bf} with a vibration amplitude of 0.8 m/s^2 at mid-mid position

4. Discussion

4.1. Seat transmissibility with the human body

A principal peak frequency was found within 4–5 Hz in TP_{cs}, consistent with the previous study [6]. The peak frequency around 4–5 Hz was less clear in the TP_{cf} than in the TP_{bf} or TP_{hf}, suggesting the pathway of vibration transmission from the floor to the cushion frame can be considered to be close to rigid and the seat foam could significantly influence the vibration transmission through the seat structure to seated human body (Figs. 5b, 6b and 7b). A reduction in principal peak frequencies with increasing vibration amplitudes was observed for all measured transmissibilities, except for the TP_{cf}, accompanied with a corresponding decrease in the peak transmissibility (Figs. 5–7). This suggests that the occupant-seat system exhibits non-linear characteristics in terms of the vibration amplitude. Kim et al. [8] reported similar findings regarding the transmission of horizontal vibration to vehicle seats. Furthermore, nonlinearities were observed in apparent masses measured at the seat back or the cushion, varying with vibration amplitudes [11], [16], [23]. Since the dynamic stiffness of seats decreases as vibration amplitudes increase, the non-linearity of the occupant-seat system may arise from both the non-linearity of the seat itself and the non-linearity of the occupant. Yet, further quantification is needed to determine their respective contributions to the non-linearity of the coupling occupant-seat system.

The TP_{cf} exhibited near unity at frequency below 20 Hz, with a minor peak observed within a range of 4–5 Hz (Fig. 5b). This indicates that the cushion frame and the potentially suspension mechanism primarily influenced the vertical vibration transmission to occupants. As frequencies approach 20 Hz, there was a slight amplification observed in the vibrations transmitted to both the frame and surface of the cushion. Consequently, the supportive frame may not be deemed rigid when simulating the dynamic characteristic of the seat at frequency exceeding 20 Hz. Comparable findings were evident in the transmissibility between to the back surface and to the seat back frame, as well as between to the headrest surface and to the headrest frame, suggesting the polyurethane foam played a dominant role in transmitting vibration to occupants. This aligns with prior studies indicating that the foam enhances static sitting comfort while reducing vibration transmission at high frequency but amplifying vibration at peak frequency [4], [21]. Around the peak frequency of 4–5 Hz, the TP_{bs} typically exhibited lower values compared to the TP_{cs} (Figs 5b and 6b). This discrepancy may stem from the compliance of the connection between the frame of the cushion and the backrest, as suggested by Vink and Lips [21]. Similarly, the TP_{hs} and the TP_{hf} demonstrated a similar pattern to that observed in the transmissibilities to the seat back.

4.2. Seat transmissibility with a manikin

The TS_{cs} and the TS_{bs} exhibited a principal peak frequency at approximately 8 Hz, with the peak transmissibilities decreasing as the vibration amplitude increased (Figs. 3 and 4). This suggests that the seat–manikin system demonstrates the non-linearity across different vibration amplitudes. Given that the manikin comprises two rigid masses interconnected, the non-linearity primarily stems from the characteristics of the seat system itself. The conclusion aligns with the findings that the dynamic stiffness of both the seat backrest and the cushion decreased as the excitation amplitude increases [28]. The vertical transmissibilities exhibited distinct characteristics between participants and the manikin. While the controlled static loading provided by the manikin may be more suitable than any arbitrary rigid mass, the utilization of the current manikin in forecasting seat transmissibilities is deemed inadequate due to its failure to accurately represent the dynamics of occupants. This study indicates that adjustments in the structure and the weight distribution are necessary when employing the manikin for the substitution for the human body. A manikin with representative dynamic responses mirroring those of seated human bodies could serve as a standardized measurement condition, obviating the need for human participants in seat tests and thereby mitigating the impact of inter-subject variability.

4.3. Impact of seat track positions on the occupant-seat system

Locking the seat at extreme track positions or leaving it moved along the track may induce alterations in the seating dynamics. In this investigation, adjusting the seat track between the extreme positions resulted in a change in the tilt angles of both the seat back and the cushion. Studies showed the peak frequency of the apparent mass measured on the seat surface increased with increasing the inclination of the rigid seat back [13]. It was also found that inclinations of the compliant seat back could alter the peak frequency and peak transmissibility in the transmissibility from the floor to the cushion surface, which was likely attributable to the influence of the inclination of the seat back on the biodynamic responses of the human body [27], since adjustments to the inclination of the seat back could change the sitting posture and the muscular force, thereby altering the vibration transmitted to and through the human body [13]. Variations of the seat inclinations could potentially change the distribution for the mass of the human body on the cushion and against the seat back, thereby impacting the seat back's ability to restrict upper body movements and consequently affecting the transmission of vibrations to the upper body. The seated weights of participants tended to be lower when positioned at the middle track position (Table 1), yet statistical analysis revealed seat track positions did not significantly affect either the peak frequencies or the peak transmissibilities. This finding aligns with prior research indicating that while participant weight correlates strongly with the apparent mass, it does not exhibit a strong correlation with seat transmissibilities [20]. It seems the combination of the changing factors mentioned above (i.e., the seat inclination, the distribution of the body mass, the sitting posture and the muscular force) did not significantly affect either the peak frequencies or the peak magnitude of seat transmissibilities and might have opposing effects on the dynamics of the occupant-seat system when adjusting the seat track between the extreme positions.

4.4. Impact of the polyurethane foam on seat transmissibilities

While the TP_{cf} approached unity, a distinct peak frequency and vibration amplification were observed in the TP_{cs} around 4–5 Hz (Figs. 5a, b). Similar phenomena were also observed in the seat transmissibilities to either the seat surface or the frame when measured with a manikin. Since the spring system is not included in this full-depth polyurethane foam seat used in the study, this suggests that the open-cell polyurethane foam plays a predominant role in the transmission of vibration to the manikin or the occupants. The open-cell polyurethane foam is widely utilized in the modern seats, and comprised of a polymer matrix where the flow of the entrapped air could influence both the dynamic and static properties of the foam [28]. The structure and property of the material forming the cell walls determines the dynamics of the open-cell polyurethane foam. Various factors, including the density, thickness, yield strength, the stress–strain relationship, and loading, may exert influence on these properties [25]. For instance, the foam with higher density demonstrates a tendency to attenuate vibrations more quickly at frequencies beyond the peak frequency in comparison to the foam with lower density [10]. Apart from the effect on the seat tranmissibilities observed in this study, the characteristics of open-cell polyurethane foam could also affect both the static riding comfort and the sitting posture, which together determine the subjective response to the whole-body vibration. Therefore, further research is necessary to assess the quantitative relationship between the subjective responses and the seat transmissibility.

4.5. Implications for the seat design and the riding discomfort

Previous research is primarily focused on the transmissibilities from the floor to the interfaces between the seat and the human body [8], [17], [28], and the influences of the vibration amplitude on the vertical transmissibility from the floor to the frame of various mechanisms of the seat has been systematically investigated in this study. It is revealed the transmissibility to the surfaces and frames of either the seat back or the headrest exhibit similar nonlinear trends, while the transmissibility to the cushion surfaces and the cushion frame shows evident differences. Future research should encompass the vibration characteristics of various seat frames, especially the cushion frame and the joints between the backrest and seat cushion, to comprehensively evaluate the mechanism of vibration propagation through the seat structure to the human body, especially to the head.

Moreover, the study demonstrates that the dynamics of vehicle seats significantly influence the vertical vibrations experienced by seated occupants. Discomfort due to vibrations is increased around the peak frequency of approximately 5 Hz, whereas the attenuation of high frequency vibrations contributes to the reduction of the transmission in the vehicle. Future research could employ the seat effective amplitude transmissibility (SEAT) for evaluating and improving the seat dynamics. This approach aims to effectively reduce the seat transmissibility at frequencies where vibrations are pronounced and the body is sensitive to the vibration, thereby minimizing the vibration discomfort [2], [18]. Furthermore, since this study showed that the seat track position did not notably impact the vertical seat transmissibility of the occupant-seat system, it is necessary to further study the mechanisms through which the seat track position influences the horizontal cross-axis transmissibility, static sitting comfort, or the influence of anthropometric parameters on seat transmissibilities. This could enhance the understanding of the dynamic interactions between the occupant and compliant seats, as well as the seating discomfort.

5. Conclusions

The vertical vibration transmitted from the floor to the cushion surface of the car seat with the human body displayed a peak frequency of approximately from 4 to 5 Hz. This peak frequency, along with the peak transmissibility, decreased as the vibration amplitude increased, indicating the non-linearity exists within the occupant–seat system under varying vibration amplitudes. The polyurethane foam material contributed to the amplification of vibrations at the peak frequency while enhancing static sitting comfort and reducing vibration transmission at higher frequencies in the vertical direction. Although the inclination angles of the seat and the distribution of the body mass were changed while moving the seat along the track the seat track position had little significant impact on the vertical vibration transmission to seats. The vertical transmissibilities measured with the manikin exhibited a significantly higher peak frequency compared to those measured with human participants. This indicated that the SAE J826 manikin employed in this study needed to be further adjusted and recalibrated for a substitute for the human body in measuring seat transmissibility.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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