Dynamic Comfort Testing of Automotive Seats in a Laboratory Setting

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ABSTRACT

The goal of this study was to use three identical looking automotive seats with different foam formulations (different stiffness, similar hysteresis) to determine whether there were differences in WBV exposures and self-reported comfort ratings across the three seats (Seat A, B, and C). Ten participants (5 male; 5 female) were recruited for this repeated-measures laboratory study. The seats were mounted on a 6 degree-of-freedom (DOF) vibrating platform on which the participants were exposed to sinusoidal vertical (Z-axis) and field-measured, tri-axial car floor vibration profiles. The participants ranked their seat preference before and after using all three seats. Self-reported seat comfort was evaluated using 7-point Likert scales at the end of each seat test. Results indicated that the least stiff seat C had the lowest resonance frequency and the lowest WBV magnitudes across all road types. Seat C was also the most preferred among the participants. This study indicates that it may be possible to improve both vibrational performance and comfort by altering foam mechanical properties through different formulations.

KEYWORDS

Vibration, Automobiles, Foam Properties, Transmissibility

Introduction

Automotive seats are one of the most important interior components when it comes to vehicle-occupant interactions as well as occupant ride and drive comfort. The seats provide support to the occupants while mitigating vibration from the vehicle floor (Ebe & Griffin, 2000, 2001). Unlike the commercial and industrial vehicles which seats have mechanical or pneumatic suspension components to mitigate vibration, passenger cars rely on the seat cushion foam for damping and vibration isolation. Previous studies have shown that foam mechanical properties such as firmness and vibration transmissibility had major influences on occupants' comfort and discomfort (Joshi, Bajaj, & Davies, 2010; Mansfield, Sammonds, & Nguyen, 2015; Mehta & Tewari, 2002; Patten, Sha, & Mo, 1998; Zhang, Qiu, & Griffin, 2015; Zagorski & Pereny, 2019). However, in these previous studies, the standardized vibration transmissibility test uses a sine sweep input, rather than the actual road profile, and such test only outputs the seat properties, instead of occupant perceptions (SAE J2896, 2012). Moreover, many of these existing studies have focused on evaluating seating comfort in the short-term and static setting ("Showroom Comfort" in the absence of vibration or motion). Hence, there is an understudied gap between the mechanical characteristics of the seats and perceived seating comfort from the occupant in a dynamic condition.
Historically, however, recent studies have indicated that Whole Body Vibration (WBV) substantially impacted occupants' comfort perception, fatigue, and vigilance, especially for long term (> 45 mins) riding and driving scenarios (Ebe & Griffin, 2000, 2001; Johnson & Neve, 2001; Park & Subramaniyam, 2013). Despite these potential adverse effects of WBV on seating comfort,

there is limited research evaluating the seating comfort in the presence of vibration exposures and investigating potential intervention to improve the comfort in automobiles.

To fill this current research gap, this study aimed to evaluate the effects of different seat properties (stiffness) on WBV and seating comfort in a dynamic environment. While the on-road test is ideal for dynamic comfort evaluation, the occupant's perception and comfort can be also greatly affected by the vibration transmitted to the occupants' hands and feet (Griffin, 2007), rather than the seat cushion only. Therefore, in order to understand how the seat cushion foam influences vehicle occupant's exposure to WBV and related comfort, it is critical to conduct a controlled study in a laboratory setting, which exclude additional environmental factors. Thus, the goals of this study were to: 1) quantify the influences of WBV exposures to the perceive dynamic comfort; 2) determine how different objectively measured foam properties affected occupants' exposure to WBV and perceived seating comfort.

Method

Test Samples (Seats): A full-size pick-up truck seat was selected for this study. The seats were built with base level attributes (i.e., only with simple adjustment functions, no heating or cooling was included) to eliminate potential bias on comfort perception. Three different cushion foams were poured for this study, among which seat B was the current production foam whereas seat A and C were produced with different chemical formulations. The seat foam mechanical properties, with the foam in a new and unused state, are shown in Table 1.

Table 1: Mechanical properties of the cushion foam pads

Seat ID	25% Indentation Load (N)	50% Indentation Load (N)	Hysteresis Loss (%)	Thickness (mm)
A	357.4	698.4	20.3	83.7
B	194.2	386.6	26.5	81.9
C	170.3	333.8	19.7	81.9

Based on these mechanical properties, seat A was the firmest, followed by seat B, and seat C was the softest (Figure 1). Otherwise, all the seat were identical in dimensions, structures, and surface materials to avoid any confounding effects.

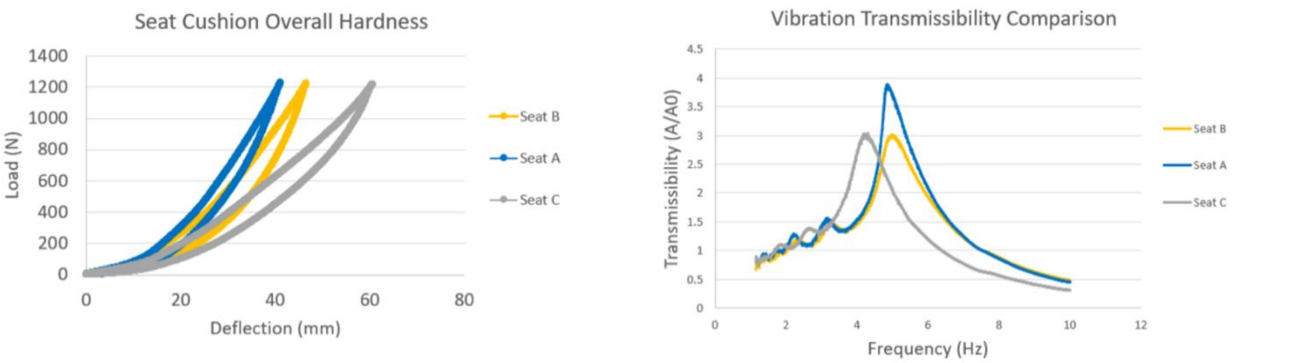

Figure 1: Baseline mechanical characteristics of three seats tested. Overall Hardness (left) and Vibration Transmissibility (right). Overall Hardness and Vibration Transmissibility measured per SAE J2896.

Test Participants

Ten participants (5 males, 5 females) were recruited via email and flyers throughout a university community (Demographics show in Table 2). All the participants had a minimum of 3 years driving experience, no existing musculoskeletal pain, and no history of musculoskeletal disorders in the neck, shoulder, back regions. Written consent was obtained from the participants prior to the study, and the test protocols were approved by the university's Institutional Review Board.

Table 2: Test Participants' Demography

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/cm²)	Driving Experience (years)
Mean ± SD	27.3 ± 6.7	169.6 ± 11.2	67.5 ± 9.8	23.7 ± 3.0	10.0 ± 6.9
Range	19 - 40	154 - 185	50 - 80	19.6 - 29.6	3.5 - 24

Test Protocols

This study used a double-blinded repeated-measure approach with a randomized order of three testing seats to minimize potential systemic bias (i.e., the first seat could receive higher score because participant has not yet fatigued from sitting). The seat cushion angle was adjusted to ensure participants' thighs were parallel to the floor while the seatback recline was set 110 degrees per ergonomic guidelines (Figure 2). Each participant sat on all three seats in a random order while being exposed to two different types of 15-minute-long vibration that were played on to 6-DOF electric-motor-based motion platform:

1) Field-measure vibration collected from the floors of a mid-size sedan (2015 Hyundai Sonata) and a full-size SUV (2019 GMC Yukon XL) while travelling over a city street, a smooth freeway, a freeway with expansion joints, a cobblestone road, speedbumps, and speed humps;
2) Vertical (Z-axis) sine sweep vibration with the peak amplitude of ±1.5 m/s^2 and frequency range of 1-30Hz.

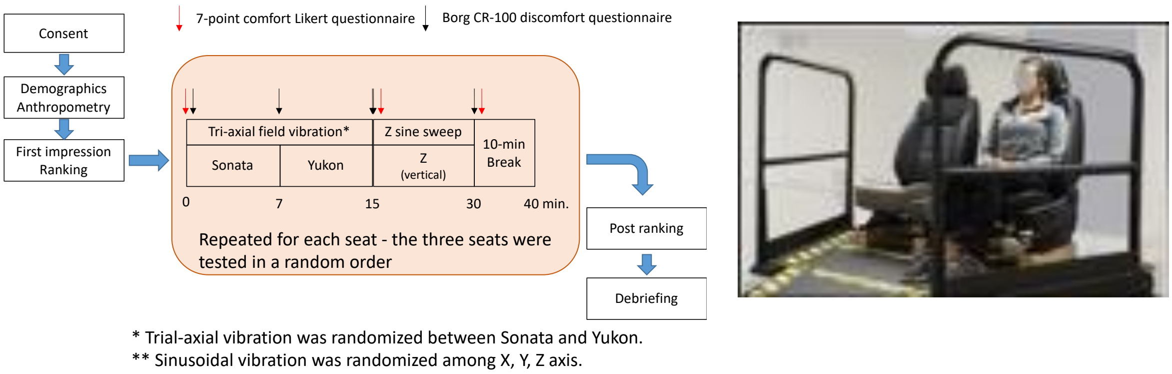

Figure 2: Test protocol (left) and test setup (right)

Outcome measures

WBV: The weighted vibration values were calculated with the methods outlined in the ISO 2631-1 standard. Power spectral density analyses were used to evaluate the vibration energy transmission and vibration attenuation properties of the three seats.

Perceived comfort: Two different questionaries were administered before, during, and after seat trial: 1) participants' preferential ranking of the three seats for comfort was collected before and after the entire protocol; and 2) A perceived seat comfort was measured using a 18-item Likert questionnaire after each seat.

Test Data Analysis

The independent variable was 'seat'; the dependent variables were WBV [A(8)] and perceived seat comfort ranking and ratings. A mixed model in JMP (Pro 13; SAS Institute Inc., Cary, SC, USA) was used to test our hypothesis that A(8) exposure and perceived comfort will be affected by the different seat stiffness. 'Seat' was included as a fixed effect and 'participant' was included as a random effect. When statistically significance was noted at the alpha level of 0.05, the differences were followed up with post-hoc multiple comparisons. In addition, the ranking data were analyzed by a chi-square test to determine the differences in rankings before and after WBV exposure.

Results

Whole Body Vibration

As seat-measured WBV were not significantly different between the sedan and SUV for the field-measured vibration profiles, the results were combined. A(8) measures were significantly different across the three seats ($p<0.0001$) and across the different road types ($p=0.002$). As shown in Figure 3, seat C had the lowest A(8) for all six different road types and performed better on the impulsive exposure conditions such as the speed bumps and expansion joints.

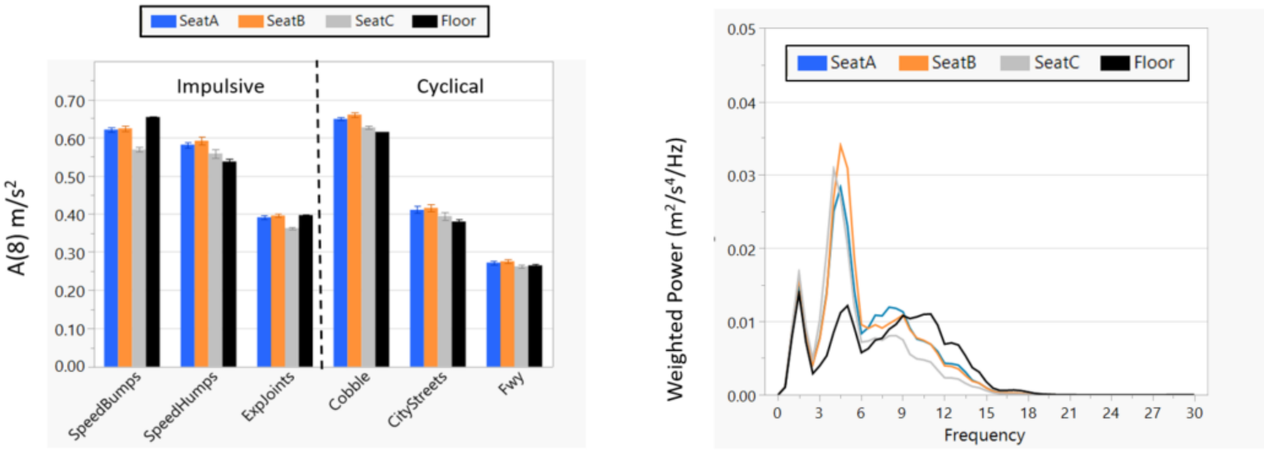

Figure 3: Comparisons of average weighed vibration [A(8)] among the three seats by different road types (left) and the average Power Spectral Density from the city street road profile (right) [n = 10].

Additionally, the Power Spectral Density analyses on the city street profile showed that seat C attenuated vibration energy above 6 Hz more so than the other seats while all three seats amplified vibration energy between 3 and 6Hz. Figure 4 showed how the tested seats performed under Z-axis sinusoidal vibration. The results showed that seat C, which was the softest from the pre-study mechanical characterization test, had the lowest resonance frequency (3.2 Hz) and greater WBV attenuation at frequencies above 6.5 Hz.

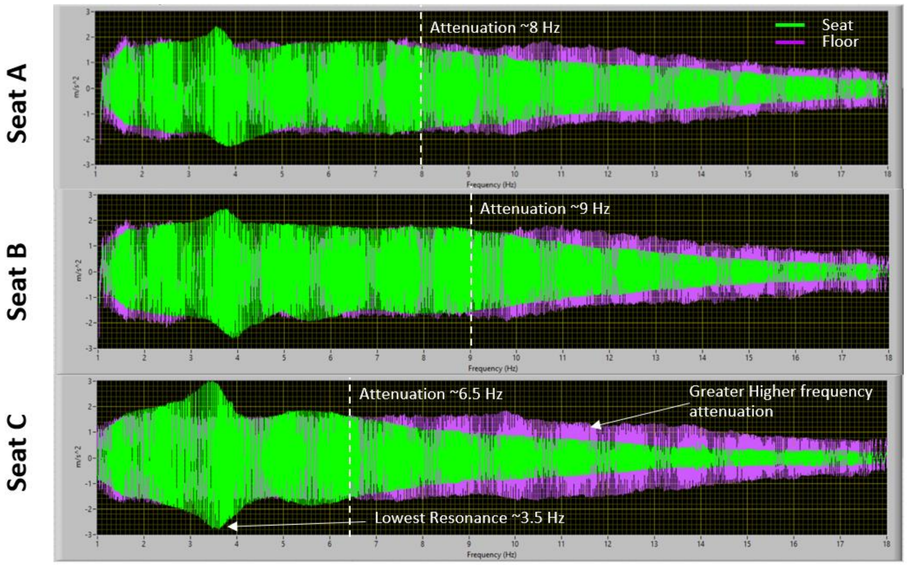

Figure 4: Comparisons of Z-axis sinusoidal whole body vibration [A(8)] comparison in a frequency domain (0-18 Hz) with the 0.5 Hz resolution.

Subjective Comfort Evaluations

With respect to seat comfort rankings (Table 3), significant differences existed initially with seat C being the ranked as the most preferred seat, followed by seat B and seat A (p=0.0015). After the dynamic seat testing, seat C still had the lowest rank; however, the differences in seat rankings across the three seats were not significant. The perceived comfort measures showed that seat C was consistently highly rated as compared to the other seats. The overall rating on seat C was significantly higher compared to other seats in comfort (p=0.02), feeling (p=0.01), and willingness to buy (p=0.03). Moreover, seat C was perceived as more comfortable in cushion firmness (p=0.02), seat pan bolstering (p=0.01), and seat pan width (p=0.01) as compare to the other seats.

Table 3: Pre- and post-testing seat comfort rankings. Lower ranks indicate greater preferences.

	Pre-Ranking (count)			Average	Post-Ranking (count)			Average
Seat	**1st**	**2nd**	**3rd**	**Ranking**	**1st**	**2nd**	**3rd**	**Ranking**
A	2	2	6	2.4	2	5	4	2.1
B	2	4	4	2.2	4	2	4	2.0
C	6	4	0	1.4	4	3	3	1.9

Conclusion and Discussion

The study aimed to evaluate the effects of potentially new polyurethane foam formulations (seat A and seat C) on WBV and comfort when compared to the current production (seat B). Both the pre-study foam mechanical characterization test per SAE J2986 and the Z-axis sinusoidal WBV exposure during the study indicate that seat C had the lowest resonance frequency. Seat C being the softest among all three seats also exceled in almost all the subjective and objective evaluations carried out in this study.

Seat Rankings and WBV: Seat C was most preferred both pre- and post- WBV exposures. Although the preferential rankings were no longer significant post- exposure, the vibration attenuation results indicated that the softness of seat C might be the differentiating factors for the initial ranking. The Z-axis sinusoidal vibration exposure further proved that seat C (softest) also had the lowest resonance frequency and started attenuating the WBV at the lowest frequency. However, the firmness differences among all three seats and the differences in vibration amplification at resonance indicate that the static foam firmness alone might not be the sole dictator for dynamic performance. From basic mechanical vibration theories, one can hypothesis that foam firmness and hysteresis might interact, and both parameters could influence dynamic seating comfort altogether.

Subjective Comfort Rating: Seat C usually had the highest comfort ratings with many of the differences reaching statistical significance. Given that three seats were identical (within manufacturing allowance) expect for the foam pads, it can be concluded that by changing the foam formulation, it is possible to alter how foam mitigates the vibration exposure to the occupant and how occupant could perceive dynamic comfort.

Limitation and Future Work: The study duration was shorter than the dynamic exposure actually occurred in on-road driving scenarios. Moreover, the occupants were sitting in the seats without surrounding vehicle attributes; therefore, the seat-occupant interactions could be simplified when compared to the in vehicle dynamic testing.

Although Seat C was most preferred in the study, indicating that foam firmness could have direct impact in long term dynamic comfort, further investigations are still needed to identify the role of foam hysteresis loss, density, thickness, and chemical formulations in energy dissipation and occupant perceptions.

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