Quantitative Investigation on Dynamic Comfort in Automotive Seats: A Ride and Drive Study

Wu PAN-ZAGORSKI[1*], Missy PERENY[1]

[1] Foam and Comfort Engineering, Lear Corporation, Michigan, 48033, USA.

* Corresponding author: Wu Pan-Zagorski, Tel.: +1-248-447-3061. E-mail address: WZagorski@lear.com

Abstract Dynamic comfort has been a heated topic within the automotive industry. Compared to the conventional static comfort assessment conducted in a laboratory setting typically used, an on-road dynamic comfort test provides more realistic and comprehensive investigation of the interaction between the automotive seat and occupant. Therefore, the goal of this study was to understand what were the major contributors to dynamic comfort and whether the occupant could perceive a difference in comfort between different seat cushions. In order to address these topics, a quantitative study including both objective and subjective evaluations was carried out. Eight participants were recruited for a 1.5-2 hour driving course that consisted of different road profiles. Each participant completed two rounds of driving with two different seat cushions installed. Participants were asked to provide subjective feedback via a questionnaire before, during, and after the driving course. The seats were also tested in the laboratory for standard objective mechanical comfort characterizations. Results showed that most participants experienced discomfort and fatigue during the entire course of driving, while a few of the participants reported muscle soreness and tailbone pain or numbness. The cushion vibration transmissibility contributed to the comfort loss during the driving. One seat cushion that was initially softer had a higher compression rate, leading to a harder feeling after the 2 hours driving course and a further decreased comfort at the end of the road test. This study supported that the short term static comfort evaluation should not be the sole decision maker when it comes to automotive seating comfort, as the participants' comfort deteriorated after a long term dynamic ride. The work presented laid a foundation for future development of automotive seats with better long term dynamic comfort.

Keywords: Dynamic Comfort, Ride and Drive, Vibration Transmissibility, Automotive Seats

1 Introduction

Seating comfort has long been discussed in the automotive industry. Comfort, by definition, not only means the "absence of discomfort", but also represents an overall wellbeing physically, physiologically and psychologically [1]. The common practice of evaluating comfort includes the assessment of the seat and the assessment of the occupant. The seat comfort evaluation dealt with the seat design and the seat mechanical properties which have been standardized by SAE J2896 in the US [2]. The occupant comfort assessment involves both objective measurement (such as body pressure distribution), and subjective evaluation which is normally recorded by questionnaires [3]. Conventionally, most of the seating comfort evaluations take places in a laboratory setting, and are either taken under static environment, or only measured within a short period of time ("showroom comfort") [3]. Recently, increased research on seat fidget has indicated that the long term dynamic fatigue plays significant role in the riding comfort. It has been reported that most people started to feel discomfort in a vehicle after 45 minutes to 1 hour of driving [4, 5], and the vibration being transmitted to the occupant over an extended period of time also has chronic impact to the occupant physiologically [6]. Therefore, it is important to carry out a ride and drive study that is longer than 45 minutes to evaluate the dynamic comfort perception of the seat.

Seat cushion foam, which provides the most direct support to the occupant, is a key player in seating comfort. The standardized measurement of the foam properties does not require the foam to be loaded over long periods of time [7] and therefore creates a gap when evaluating the long term mechanical properties of the foam and the occupant seating comfort.

In order to better understand the overall comfort performance of the seat, a dynamic ride and drive study with both subjective and objective measurements is needed to quantitatively evaluate the differentiable comfort contributors of automotive seats. Hence, the goals of this study were to investigate: 1) the major contributors to dynamic comfort; 2) the influence of seat cushion foam to occupant comfort over a long term driving period.

2 Method

A mid-sized 4-door sedan at a medium price range was chosen to be the test vehicle. Two different cushion foams (here in after referred as Foam A and B) were selected as the comparative targets for this study. These two foams were made from different chemical formulations but kept the same density. Foam A was slightly softer than Foam B per standard test results. The mechanical properties of the foams per ASTM test method [7] are listed in Table 1.

Table 1. Mechanical Properties of the Two Cushion Foam Pads

Foam ID	*25% Indentation Load (N)*	*50% Indentation Load (N)*	*65% Indentation Load (N)*	*Hysteresis Loss (%)*	*Thickness (mm)*
A	293.03	528.78	905.72	31.04	73.5
B	295.43	542.65	959.51	29.98	72.7

Three 3-axis accelerometers (TLD356A15, PCB Piezotronics, USA) were instrumented on the seat (Figure 1): one at the front end of the seat track; one at the rear end of the seat track; one hidden underneath the trim cover towards the rear end of the cushion foam. A handheld 12 channel data acquisition device (Coco-90, Crystal Instruments, USA) was used to collect the vibration data while on the road. In this study, we focused on the comfort impact of vertical vibration, therefore the vibration transmissibility was calculated as the ratio of the vertical acceleration power density between the cushion and the seat track.

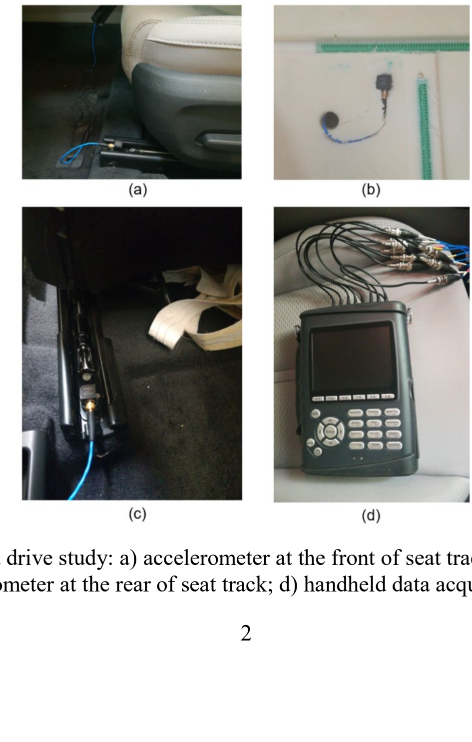

Fig. 1. Instrumentation of the ride and drive study: a) accelerometer at the front of seat track; b) accelerometer in the seat cushion; c) accelerometer at the rear of seat track; d) handheld data acquisition device

Eight participants (6 male; 2 female) were recruited in this study on a voluntary basis. None of the participants had known existing health conditions that would prevent them from driving for 2 hours continuously. All of the participants drove on a daily basis and their daily commute time varied between 20 minutes to 1 hour and 45 minutes one way (home/work). The average height and weight information of the participants are listed in Table 2.

Table 2. Participant Information

Sex	*Number*	*Ave. Height (cm)*	*Ave. Weight (kg)*
Male	6	177.0	77.1
Female	2	165.1	55.6

The driving route chosen for this study consisted of different road profiles: city street, highway, dirt road, freeway, and suburban roads (Figure 2). The total distance of the entire route was 88 kilometers.

A customized questionnaire was designed and used to collect subjective feedback before, during, and after the driving course. Due to concerns of inducing fatigue to the participants, the ride and drive test for each participant was taken in two rounds, i.e. the participant drove the vehicle with Foam A in the seat first, then drove the vehicle with Foam B on a separate day. Since comfort is a measure of overall well-being [8, 9] and is affected by not only physical but also physiological factors, we asked the participants to provide a rating of their overall general comfort feeling (in addition to seat comfort ratings) both at the beginning and the end of each round of the driving test. Therefore, instead of having the participant make preferential evaluations between Foam A and Foam B, the study aimed to provide a direct comparison by calculating the comfort level decrease at the end of driving test for Foam A and Foam B respectively. During the drive evaluation, the same set of questions was repeated for each road profile to see which road condition caused most discomfort for the participant.

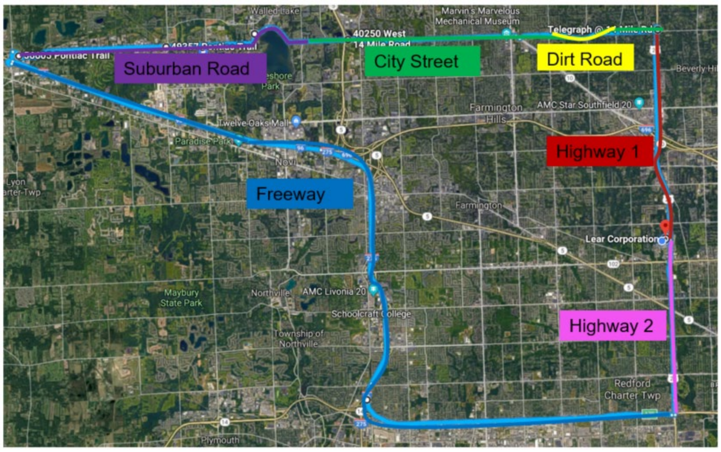

Fig. 2. Different road profiles in the driving course.

In order to gain both objective and subjective insights for the comfort performance of the seat cushion, the standardized mechanical testing for both seat cushions was performed according to SAE J2896. Additionally, a special vibration transmissibility test was carried out: after the initial J2896 vibration transmissibility test, the seat was continuously loaded with 50kg weight for 2 hours and then repeated with the J2896 vibration transmissibility test. Therefore, by comparing the vibration performance change over the 2-hour loaded period, it provided the ability to correlate the objective measure with the subjective scores from the ride and drive study.

3 Results

The ride and drive vibration transmissibility was presented as the ratio of peak acceleration Auto Power Density (APS) between the seat cushion and both of the front and rear seat tracks. The on-road comparison between Foam A and Foam B in vibration transmissibility is shown in Figure 3. It can be seen that both foams yielded good vibration absorption (lower transmissibility) performance. On the dirt road, Foam A had higher transmissibility than Foam B. However, no significant difference was observed.

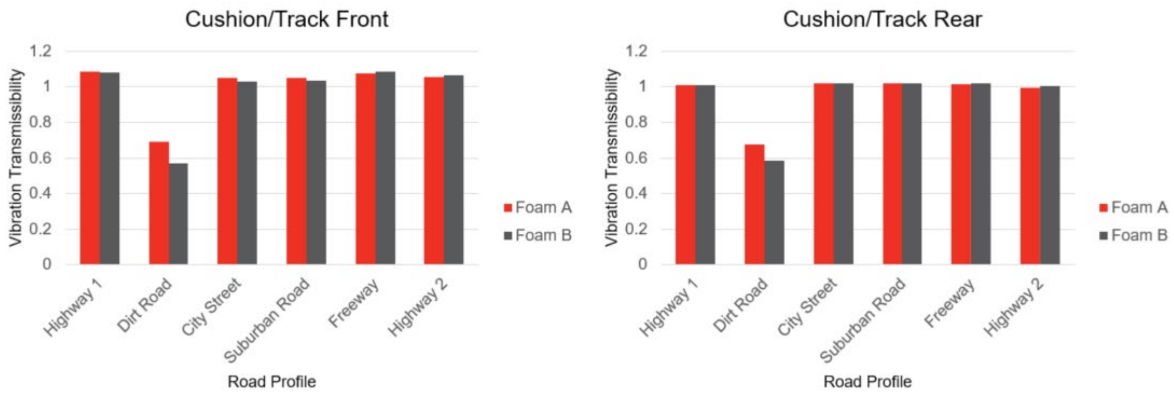

Fig. 3. Vibration transmissibility comparison between Foam A and Foam B on different road profiles

Figure 4 shows the subjective comfort rating change after the 1.5~2 hour drive. Foam B exhibited less comfort loss when compared to Foam A. In other words, Foam B maintained more comfort compared to Foam A after 2 hours.

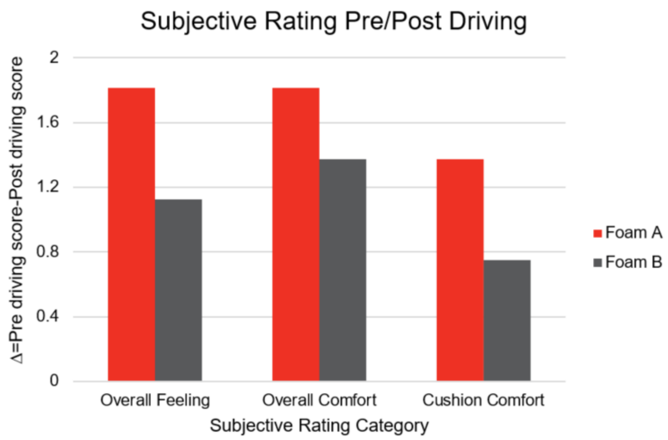

Fig. 4. Change in subjective rating before and after driving test

Additionally, during the specially designed 2-hour in-lab vibration transmissibility test, we have found that both foams had increased transmissibility after sustaining the 50kg load for 2 hours. Foam A had a higher increase in the transmissibility than Foam B. This result provided a possible explanation for the larger comfort loss of Foam A when compared to Foam B at the end of the ride and drive study. From the overall hardness testing, based on SAE J2896 methodology, we also found that Foam A had significant increase in the hardness after 2 hours' loading. This could be a result of air being pushed out from the open cell foam, increasing the stiffness of the foam. The increased stiffness also led to the increase of resonance frequency of the foam pad, as can be seen from Figure 5. These 2-hour mechanical performance results were echoed by the subjective feedback: half of the participants reported the cushion hardness feeling had changed for Foam A at the end of the driving, and one participant reported a sinking feeling of Foam A at the end of the drive evaluation.

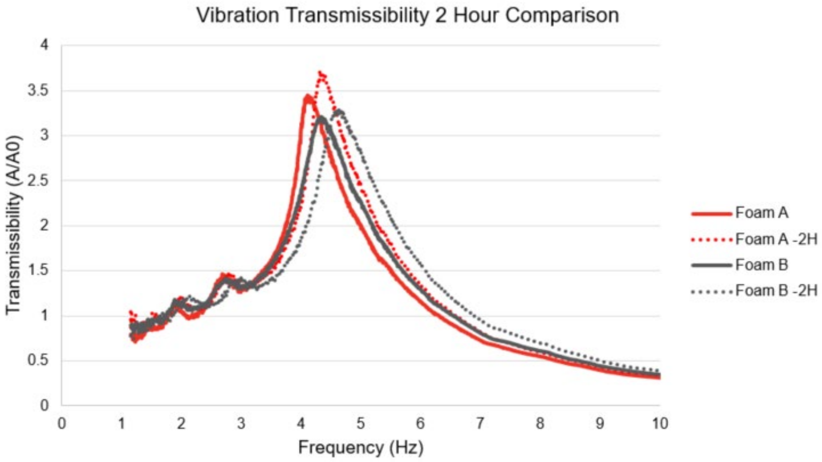

Fig. 5. Vibration transmissibility comparison of Foam A and Foam B before/after 2 hours loading

All eight participants reported body fatigue with Foam A and six of the eight participants also felt fatigued with Foam B. The most reported fatigue and discomfort types include numbness in the buttocks, lower back muscle soreness, and tailbone burning sensation. Only two participants reported discomfort from vibration on dirt road, this could be because the dirt road occurred at a relatively early phase of the drive route.

4 Conclusion and Discussion

Dynamic seating comfort has raised more and more awareness in the automotive industry, especially with the increased focus on interior design leading into the autonomous vehicle era. The study presented here quantitatively compared both objective and subjective ratings of the two different cushion foams and provided insights into the lead contributors to seated occupant comfort during long-term driving experience.

The results indicated that the foams' mechanical properties (both overall hardness and vibration transmissibility) would change over extended periods of time when under a loaded condition. These data supported that it is important to differentiate between showroom static comfort and long-term driving comfort. Additionally, the long-term performance of the seat cushion is perceivable by the occupant as participants did report changes in the feel of cushion firmness. Hence, a long term dynamic comfort evaluation is needed to provide a comprehensive assessment of automotive seat comfort.

We would like to point out that one of the innovative approaches used in this study was the instrumentation of the accelerometer in the seat cushion. Traditionally, researchers have been using a transmissibility pad to measure seat transmissibility. However, we have found out that the pad itself would cause extreme discomfort even under static condition. As the goal of this study was to evaluate the dynamic driving comfort, we wanted to maintain the vehicle interior condition as close as possible to the realistic driving condition.

5 Limitation and Future work

The major limitation of this study was the limited sample size for both seat samples and number of participants. In this study, two cushion foams were used. Although these two foams had the same density and similar firmness, there might be other material properties that contributed to the comfort but were not taken into consideration in this study. Additionally, due to the availability of the participants, we had constraints on the driving time. Some participants commented the comfort feeling could change depending on the time of the day or the day of the week.

Even with the limitations discussed above, we were able to see a meaningful difference between the two foams during long term driving. This study laid a foundation for comprehensively understanding the seat dynamic comfort performance. We would like to continuously adopt a similar methodology and collect more data in the future to enhance our knowledge base in long term dynamic ride and drive comfort.

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