Psychoacoustic Bias in Vehicle Interior Noise – Preliminary Study

M. Farid Aladdin1, 2* and Nawal A. Abdul Jalil1

1 Sound and Vibration Research Group, Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Putra Malaysia, 43000 UPM Serdang, Selangor, Malaysia.
2 School of Engineering, Taylor’s University Malaysia, Jalan Taylor’s, 47500, Subang Jaya, Selangor, Malaysia.

Abstract

This paper presents a preliminary study of psychoacoustic response bias in vehicle interior noise. The subjective response in psychoacoustics require human subject with relevant background and tendency for the best data analysis. In the vehicle interior sound quality subjective investigation, different vehicle owner have different expectation in vehicle comfort based on their preference. The perception and hearing sensitivity will be based on their day-to-day exposure. The objective of this paper is to study the bias response in vehicle sound quality judgement for different categories of car user (such as compact, sedan and luxury car). In this study, a survey has been conducted in an automotive service workshop. The questionnaire was designed to obtain the perception towards overall vehicle interior noise. The questionnaire are divided into three section; Part I: demographic information, Part II: Customer comfort level on level in vehicle cabin, Part III: Customer comfort level of sound loudness. The part III questions is created based on Loudness Fastl’s Thermometer. The respondents were given brief demonstration of loudness and sharpness. Two examples of each type were given to assist respondent in grasping the concept and come out with their judgement toward the related sound mentioned in the survey. In this study, 30 male and 12 female respondents participated in the survey. The results showed 80% of the respondents feel comfort with their respective vehicle regardless of what type of car there are driving. This indicates clear bias response based on the user’s experience in driving different type of car. In a nutshell, different car owner define comfort level differently. Even if the sound level is different in comfort, sedan and luxury car, the driver still feel comfort which lead to different perception in defining vehicle cabin interior noise comfort.

1. Introduction

Psychoacoustic is a field where objective and subjective evaluation are integrated to simulate sound quality of a product. In automotive noise, vibration and harshness (NVH), vehicle cabin noise has been an important factor in determining the sound quality of a car. Nowadays the sound quality research of vehicle is heading towards defining suitable sound for specific purpose and expectation. In general, vehicle cabin noise consist of structural borne and air borne noise which dominate the perception of sound to vehicle driver or passenger. In general, the structure-borne noise transmission path dominates at low frequency (<200 Hz), the air-borne noise transmission path dominates above 500 Hz and in the mid-frequency range, both transmission paths have usually the same level of importance [1]. Psychoacoustics investigation of sound quality in automotive industry concern practically all sounds present in the vehicle’s acoustics environment, such as door-closing sound, starter sound, engine noise, tire noise, wind noise, power window sound, air condition system noise and sound produced by car audio system [2]. In practical application, two main interest related to sound quality investigation are sound evaluation and sound quality engineering. The different between both investigations is that sound evaluation deals with improvement of existing sound and sound quality evaluation.
In sound quality measurement, different type of car have different interior sound level. This will lead to tendency of car driver or passenger to get use to certain level of sound which turned into expectation or perception. Therefore it will expected that biasness will happen if perception of human subject is used for subjective evaluation. In compact car, vehicle interior noise level will increase with time. At speed of 60 km/h, the noise level can reach 60 dBA whereby at the speed of 120 km/h, the sound level will reach 70 dBA [5]. This will create a norm to the driver when they get used to the sound environment and created perception in noise comfort. Therefore if they are presented with the same level of noise, it will reach their expectation of comfort. In B segment car, the interior sound could reach 61.2 dBA at the speed of 60 km/h and as the speed increased to 100 km/h, the sound level can reach 62.2 dBA [6]. Instead of having sound pressure level, it is not good enough to give a definitive result of sound experience. Psychoacoustic metrics such as loudness, sharpness, fluctuation strength and roughness are the most suitable parameter to objectively quantify the sound experience. In current practice of sound quality engineering, psychoacoustic metrics are considered to be the most suitable indicator to quantify sound perception by human. The parameter of Loudness, sharpness, fluctuation strength and roughness will describe the sound spectrum for all audible frequency level in quantifying sound annoyance to human. Other than that, one of the method to investigate noise comfort is through subjective investigation such as jury test session. Basically the idea of this session is to get the real response of human towards sounds. The sound of vehicle cabin will be recorded with binaural technique and later will be reproduced over headphones to the listeners. The live real-time sound is not used to prevent inconsistent sound production during the session. It is important to reproduce the sound which resemble the real sound which encountered by vehicle user. Binaural recording will take into consideration the effect of human head, outer ear shape and torso to sound received by ears. In this study three main questions will require special attention; How bias happen in subjective response experiment? Will different car user have different perception? How can we verify they have different perception? Our hypothesis is that bias will likely to happen during subjective investigation based on several factors related to human subject background. Therefore the objective of the study is to understand the bias condition of different car user and analyze how the bias condition happen under different types of car owner with different drive condition. This is the factor which believed to be the root cause of bias to happen in performing jury test or other subjective method test.

2. Methods

In this study, a set of questionnaires was prepared to get human respond towards sound based on their life experience, not based on sound reproduction. This initiative had been taken because due to one important issue where the respondent are not trained to evaluate sound accordingly. This will create stress among subject which could lead to incorrect data. By doing survey, subject or respondent will have sufficient time to respond accordingly based on their life experience towards the sound of interest. In addition, it will be a good findings to get respond from real customers from automotive workshop or service center who are critical in giving feedback and complain. The survey activity centralized in D’Alpha Auto Service Center in Shah Alam region, Selangor, Malaysia. It is an automotive service and diagnose center which specialized in computerized diagnosis and troubleshooting. The target respondents are the waiting customers. However technical staff and workshop management also take part in this survey to support the activity.

<table>
<thead>
<tr>
<th>Driving experience</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5 years</td>
<td>13</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>6 – 10 years</td>
<td>16</td>
<td>38.1</td>
<td>69</td>
</tr>
<tr>
<td>11 – 15 years</td>
<td>8</td>
<td>19</td>
<td>88.1</td>
</tr>
<tr>
<td>16 – 20 years</td>
<td>5</td>
<td>11.9</td>
<td>100</td>
</tr>
<tr>
<td>Others</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
2.1. Survey structure and procedure

The survey was conducted in the workshop office. In this survey, 42 respondent participated, 30 male and 12 female with age mean of 35.9 years and standard deviation of 12.43. In term of driving experience, 38.1 percent of the respondents have 6 to 10 years driving experience and 30 percent have driving experience more than 10 years as in Table 1. The questionnaire were divided into three sections - Part I: demographic information, Part II: Customer comfort level on noise level in vehicle cabin and Part III: Customer comfort level of sound loudness. The Part III questionnaire is created based on Loudness thermometer by Fastl as in Figure 1.

![Fig. 1. Level-thermometer and loudness-thermometer adapted from Fastl [3]](image)

The level-thermometer and loudness-thermometer are the indicator of sound and its respective value of sound level and loudness. It shows that jack hammer is having the loudest level of sound as compared to others. However, an interesting fact to see here is that some sound which has high sound level happen to have lower loudness level. For example, the sound of trumpet shows a higher sound level dB (A) value than the lawn mower, but has lower value in loudness Sone scale. The differences is caused by different spectral distributions of the related sounds. It can be seen also when we see the violin sound which produces the same sound level dB (A) value as an electric drill, but with a lower level of loudness. This Thermometer level is the basis of the questionnaire Part III where we expect the respondent to rate the respective sound loudness accordingly from loudest (jack hammer) to the lowest loudness level (ticking alarm clock). However in the questionnaire, the lowest level was taken to be normal conversation.

2.2. Survey rubric and relation to biasness of sound perception

Before the session, respondnet were briefed on the five level of sound comfort scales. The description as in Table 2 below. It is important for the respondent to understand the expectation of each comfort level. They will need to match their experience in listening the related sounds with the comfort level. This procedure is different from the usual technique of sound reproduction in jury test. The respondent were required to approximate the sound level based on their experience, instead of judging and rating the sound. This can reflect the perception of human towards certain sound because judging real-time sound require a well-trained hearing and for random vehicle users, this ability might be lacking.

<table>
<thead>
<tr>
<th>Level</th>
<th>Comfort level</th>
<th>Sound Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Very comfortable</td>
<td>Sound heard very lightly and not affecting driving experience</td>
</tr>
<tr>
<td>4</td>
<td>Comfortable</td>
<td>Sound heard but not affecting driving experience</td>
</tr>
<tr>
<td>3</td>
<td>Less comfortable</td>
<td>Sound heard and slightly affecting driving experience</td>
</tr>
<tr>
<td>2</td>
<td>Disturbed</td>
<td>Sound heard and causing discomfort in driving experience</td>
</tr>
<tr>
<td>1</td>
<td>Extremely disturbed</td>
<td>Sound heard very annoying and cannot be exposed in long period</td>
</tr>
</tbody>
</table>
2.3. Survey effectiveness and expectation

The randomness of the survey is believed to give the real perception from vehicle user. The procedure and material of the survey were made as simple as possible with the hope that customer will reflect their closest perception to the condition given and lessen the tension during survey. The environment for survey is just a typical automotive workshop customer waiting lounge. The questionnaire is prepared in Malay language as to prevent any language barrier. The customer will fill up the questionnaire in the laptop and save in the indicated folder. The process of the survey per person is about 10 minutes including explanation session.

2.4. Psychoacoustic metric and customer understanding

The concept of psychoacoustic metric such as loudness, sharpness, roughness and fluctuation strength were explained briefly to customer in layman term. This is very important so that customer have some understanding of how to gauge the sound that they can recall. Loudness can be easily explain as perception of the amplitude of sound signal [7]. The higher the amplitude, the louder the sound will be. The sharpness is the perception of sound due to its frequency. The sound with higher frequency will cause sharp sound to human ears. 2 samples of loud and sharp sounds were presented to respondent to increase the understanding and assist them to make evaluation. The sample sound also based on the level-thermometer and loudness thermometer by Fastl as in Figure 1. For sample number one, the respondents were presented with violin sound of 50 sone and trumpet with 62 sone. For sample number two, the sound of bird twitter with sound level of 60 dBA and sound of normal conversation of 70 dBA were presented.

3. Results and Discussion

Figure 3 shows the percentage of customer sound comfort level for vehicle under stationery condition and conversation clarity in vehicle cabin under stationery condition. It shows that 36 respondents feel extremely comfort and 6 feel comfort. This
indicate that 100% of the respondents satisfied with the sound level of their respective vehicle under stationery condition. In other condition, only 1 respondent from sedan car feel less clarity in conversation under stationery condition. The findings indicate that the comfort level of vehicle user is based on the car they drive. Therefore different car user have different definition of comfort which will create bias in psychoacoustic respond.

![CUSTOMER SOUND COMFORT LEVEL UNDER STATIONERY CONDITION (VEHICLE STARTED)](image)

(a)

![CUSTOMER SOUND COMFORT LEVEL OF CONVERSATION CLARITY UNDER STATIONERY CONDITION (VEHICLE STARTED)](image)

(b)

**Fig. 3.** Customer sound comfort level for two different condition; under stationery condition (a) and conversation clarity (b)

For vehicle in motion, two conditions of speed are taken under consideration. The speed of 60 km/h and 120 km/h represents city drive and high speed on highway respectively. As expected based on the hypothesis, at the speed of 60 km/h, 41 of the respondents from all type of cars feel comfortable and extremely comfortable with their cars as shown in Figure 4. The percentage of extremely comfort dominate the comfort level with average of 80% respondent. Only 1 respondent from compact car type feel less comfortable. At speed of 120 km/h, perception of respondent started to be affected as only 2 respondents (11.1%) for luxury car and none for other two types of car. All the three types of car are rated comfortable by the respective respondents with average 30 respondents (71%) agreed on it. Instead of feeling comfort, 2 respondents from sedan and compact car started to feel disturbed at this high speed. Again these figures show that different car type customer have their own definition of comfort.
In psychoacoustic study, other noise source in vehicle cabin were also surveyed to get the sound which define the purpose and not causing discomfort to customer. For example noise from a vehicle door closing has two main function; first is to indicate the door was properly closed, secondly to give good impression to customer [8]. In Figure 5, the percentage shows that luxury car and sedan car customer extremely comfortable with the sound turning on the air condition system even though in actual the sound level and loudness might be different. This will create bias in term of deciding the correct “extremely comfort” level. What comfort for sedan car might not be comfort for luxury car customer and vice-versa. Customer from compact car just feel comfort rather than extremely comfort. This is aligned with initial expectation as compact car customer expose more on high sound level and loudness therefore less sensitive to differentiate comfort and extremely comfort. Therefore this findings also indicate customer from different car type have their own definition of comfort.

![Customer sound comfort level while vehicle in motion at 60 km/h](image)

![Customer sound comfort level while vehicle in motion at 120 km/h](image)

**Fig. 4.** Customer sound comfort level for two different condition; vehicle in motion at 60 km/h (a) and at 120 km/h (b)
Fig. 5. Customer sound comfort level for two different condition; turning air cond system (a) and door closing and opening (b)

The sound loudness scaling indicate that luxury car customer is more sensitive toward sound loudness compared to sedan and compact car user and able to scale the sounds according to loudness thermometer. In this section, 30 out of 42 respondent managed to scale the sound loudness accordingly where 50% of them were customer from luxury car as in Figure 6. Different car customer perceive loudness differently. For example 70% of luxury car customer rate lawn mower loudness as disturbance but not for sedan and compact customer. They have different perception towards the sound. This could lead to bias in subjective evaluation which concern human perception. However this is based on customer experience and not real-time sound evaluation. In term of comparing overall comfort for different type of vehicle, it can be seen from figure 6 that all type of vehicle are having high comfort percentage in all category which indicate the user overall satisfy with the interior noise level in their respective car. However the most dissatisfaction comes from compact car user. This finding is within expectation since by comparison, compact car will have the highest sound level in all the conditions mentioned in the survey compared to luxury car and sedan car.
In conclusion, the findings suggest that the perception of different car user is varies based on sound exposure. The luxury car driver comfort and annoyance level is not the same as sedan and compact car driver. On the same condition in vehicle cabin, the findings suggest that user perception of comfort is based on their norm regardless of the fact that they are undergoing different sound environment. The user feel comfort at different sound level environment. This will create bias in defining comfort. The contribution of this work is to explain how bias happen between different car user. The future work for this study would be to verify the finding by performing the jury test with psychoacoustic metrics analysis of all three types of car; luxury car, sedan car and compact car, respectively.

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References


