A Study on sound quality evaluation index of car door latch and improving sound quality by modifying door latch assembly design

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ABSTRACT

The purpose of this study is to develop an index that evaluates the sound quality of the door latches and improves the sound quality based on the results. To conduct the jury evaluation, various operating sounds of door latches were used. Through the results of the jury evaluations, loudness and sharpness related metrics are dominant in the sound quality index we developed. This research investigates the main transfer path of operating sounds through sound field visualization and concludes what could reduce the impact sound of the door latch. Therefore, we could verify the sound quality improvement of modified products by using the sound quality index.

Keywords: Preference testing, Transients and shocks, impacts

1. INTRODUCTION

Due to advances in technology and improvement in income levels, high-end cars have been gradually becoming the new propensity of consumers of cars. The meaning of consumption of cars has been transformed from the acquisition of transportation to the possession of an item that supports a luxurious and convenient life. As a result, car NVH research, which had been focused on reducing noise and vibration, began to be interested in emotional factors such as luxury, reliability, and so on.

The door latch has a great influence on the reliability of the automobile because it is the part that is directly connected with safety. Through the sound of the door latch, people feel a sense of security that it is locked well. On the contrary, if the sound is not adequate, people feel anxiety. Another feature of the sound of the door latch is that it is recognized clearly while driving.

According to the past trends of NVH research, to improve its sound quality, of course, we can reduce the sound pressure level using acoustic absorption materials. But we do not want to simply reduce the sound pressure level. In this study, our goal was to improve the sound quality of the door latch, which has a major impact on reliability and the sense of luxury of vehicles. We established a standard for evaluation of sound quality of the door latch through the jury evaluation and analysis of sound characteristics. Furthermore, we developed a way to improve the sound quality of the door latch.

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2. ANALYSIS OF OPERATING SOUND OF THE DOOR LATCH

As shown in figure 1, the sound of a door latch while operating consists of an ‘impact sound,’ which is the main sound; and ‘residue sound,’ which is generated by the motion of the gear moving back to its original position. Both sounds are impulsive sounds that vanish after a short duration and excite a wide frequency range. The interval between the sounds, which is different according to the model of the door latch, is generally from 0.2 sec to 0.5 sec.

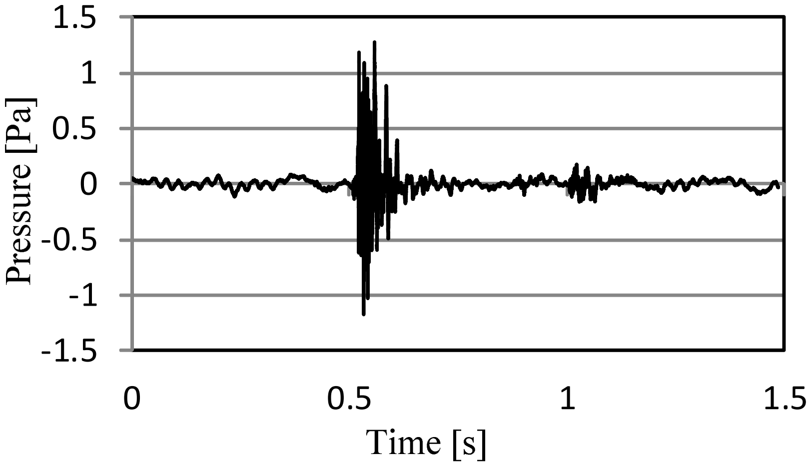

Figure 1 – Operating sound of Door Latch

Operating of the door latch is separated into a ‘closing’ motion and ‘opening’ motion. Each operating sound could be discriminated by hearing. In this research, the jury test and analysis of the sound was conducted separately by ‘locking’ motion and ‘unlocking’ motion to discriminate the correlation and difference between the two operating sounds. Figure 2 and 3 show the characteristics of the different motion of the same model. The interval of the impact sound and residue sound, and frequency range when the impact sound is generated are the main differences that stick out.

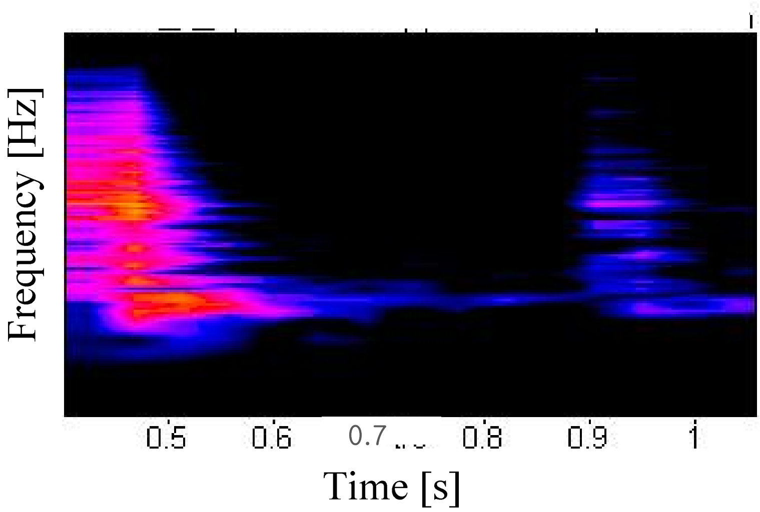

Figure 2 – Time-frequency property of ‘Locking’ sound

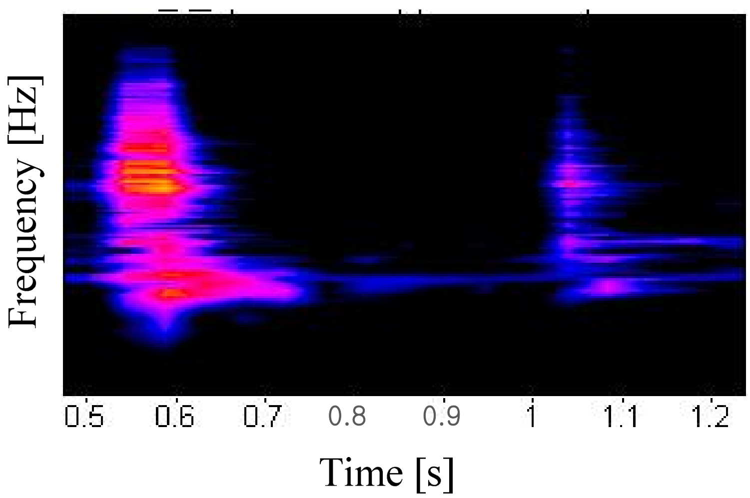

Figure 3 – Time-frequency property of 'Unlocking' sound

3. SUBJECTIVE PREFERENCE BY JURY EVALUATION

3.1 Recording methods

This study was conducted with the door latch. The sound samples that were used in this study were obtained by recording the door latch directly in a real car put in an anechoic chamber. The samples were recorded under the condition of an idle engine state by a man sitting down on a car sheet and wearing headset microphones (BHS II, Head Acoustics). The headset microphones' range of frequency response was 20Hz-20kHz, and the maximum SPL 130dB. We used headset microphones because we could consider the binaural characteristics of human ears with them. For accurate objective analysis, we recorded the sound samples 5 times for each car. Among them the finest one, which had no abnormal sounds, was used for the jury test.

3.2 Method of jury evaluation

The rating method was used to investigate the subjective preference. The rating method is the process the jurors use to give a score to each sample independently after listening to sounds of the samples. The rating method could achieve higher reliability than other more novice methods of jury evaluation which easily lose their concentration because it is easy to evaluate and takes a short time.

Figure 4 is Risa of Ricardo, which was used in jury evaluation in this research. Jurors only evaluate by sounds without knowing the models of cars and they provide a score ranging from '0 to 1.'

Also, jurors give the reason for the score and comments are used as subjective characteristic data analysis.

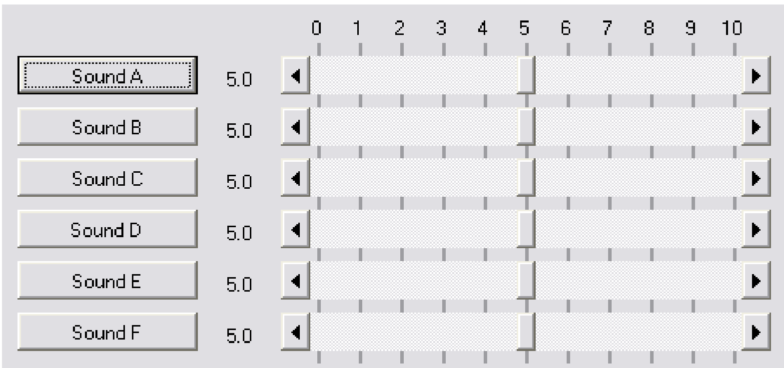

Figure 4 – Risa (Corp. Ricardo) used in jury testing

A total of 8 cars were used in the jury test, which includes a variety of engine displacement and company. 16 samples, which were 8 opening motions and 8 closing motions, were used because the sounds of the opening motion and closing motion are different.

3.3 Results of the jury evaluation

Figures 5 and 6 present results of the jury evaluation of the closing motion and opening motion of each door latch. Car 5, which took 1st place in both the closing and opening motion, has the smallest engine displacement; and Car 6&7, which had a lower score, had quite a large engine displacement. Therefore, the preference b the door latch operating sound and engine displacement did not have big correlation.

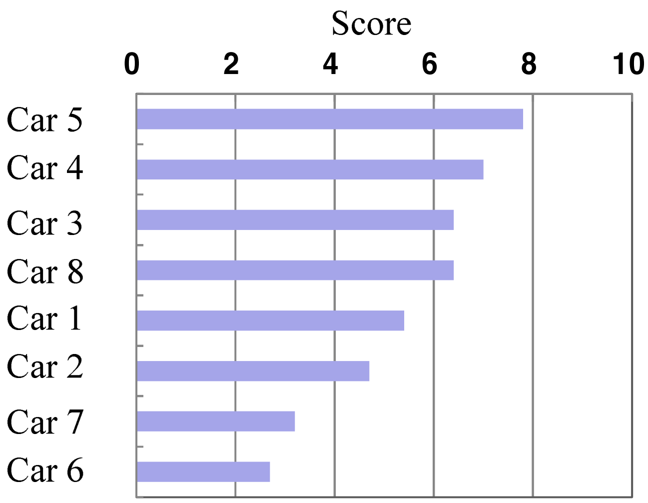

Figure 5 – Result of jury testing using ‘Locking’ sound

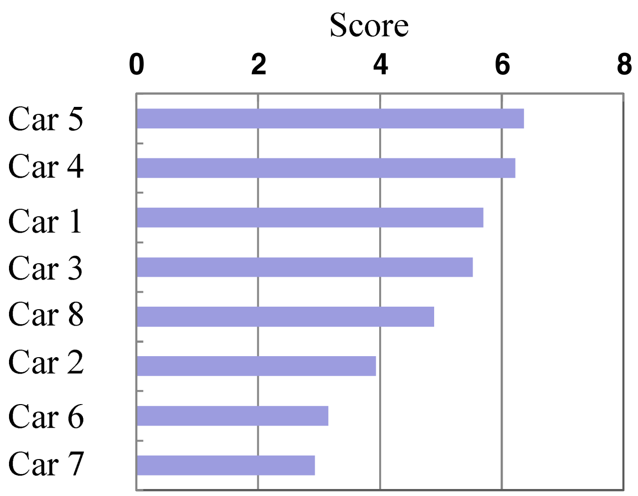

Figure 6 – Result of jury testing using ‘Unlocking’ sound

Figure 7 is the preference correlation between the locking sound and unlocking sound. As shown in the figure, there are meaningful correlations between the two sounds, which show different characteristics in sound properties.

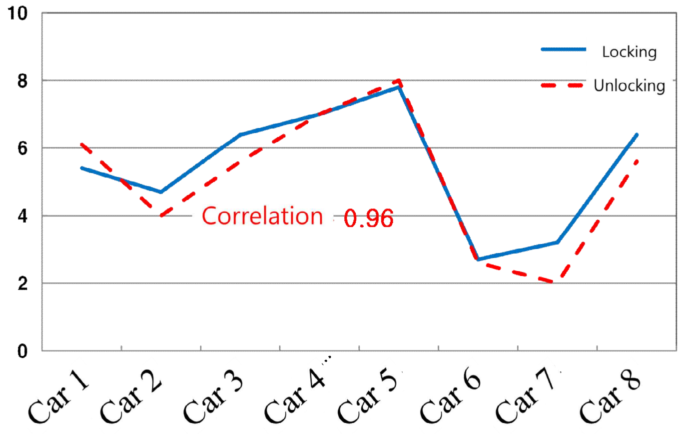

Figure 7 – Preference correlation between 'Locking' sound (red, solid) and 'Unlocking' sound (blue, dash)

4. SOUND QUALITY INDEX DEVELOPMENT OF DOOR LATCH

4.1 Objective metrics

To develop the sound quality index, it was necessary to analyze the correlation between the subjective preference and objective characteristics of the sound. The objective metrics used in this analysis are shown in Table 1 and were selected by the comments of the jurors when conducting the jury evaluation. L_n(n:1~5) is loudness related metrics of sound of the door latch. And S_m(m:1~9) & T_l (l:1~4) are sharpness related metrics and time related metrics of sound of the door latch, respectively.

Table 1 – Selected objective metrics based on the results of interviews

Subjective expressions	Engineering expression	No. of selected metrics
'Quiet', 'Too loud', 'Noisy', etc.	Loudness related(L)	5
'Too high frequency', 'light sound like toy', 'luxurious sound of bass', etc.	Sharpness related(S)	9
'Opened smoothly', 'late residue sound', etc.	Time related(T)	4

Most of the jurors considered the level of the operating sound a problem when asked about which ones make the operating sound feel luxurious. Roughly, jurors disliked and did not feel luxurious about a very loud sound. Jurors considered the tone of the sound more important than the level of the sound. Below a certain level of sound a problem does not occur; however, the tone of the sound while opening or closing the door is related to the reliability of the product. Also, jurors commented on frequency related words like disliked high frequency sounds or prefers low frequency magnificent sounds. Apart from these comments, some jurors felt inconvenient about the long interval between the impact sound and residue sound.

Metrics influence the luxuriousness of the operating sound and were chosen based on the comment of the jurors. The level and sharpness of the sound, and time-related metrics are expected to be prime metrics. A total of 18 metrics were included: 5 level-related metrics, 9 sharpness-related metrics and 4 time-related metrics.

4.2 Sound quality assessment index for the door latch

We conducted regression analysis using the metrics selected through the jury test and found the most well-explainable equations. Equations 1 & 2 are a sound quality assessment index of 'locking' and 'unlocking' sounds, respectively. Both equations have L_1 and S_6 as important main metrics. As shown in the equations, the quieter and less sharp the sound the higher the score it gets.

$$SQI_{Lock} = 27.15 - 0.23\ L_1 - 6.60\ S_6 \tag{1}$$

$$SQI_{Unlock} = 23.68 - 0.16\ L_1 - 8.10\ S_6 \tag{2}$$

Table 2 & 3 are standardized contributions of each metric. According to the results, S_6 is a more important metric than L_1. This means that the sound quality of the door latch is affected by sharpness more than loudness. Simply speaking, lowering the frequency is a more effective way to improve the sound quality of the door latch than reducing sound level.

Table 2 – Regression statistics of SQI of door latch 'Locking' sound

	SE Coeff.	P-value	R-sq(adj)
SQI		0.003	
L_1	0.03	0.005	90.8 %
S_6	3.93	0.15	

Table 3 – Regression statistics of SQI of door latch 'Unlocking' sound

	SE Coeff.	P-value	R-sq(adj)
SQI		0.002	
L_1	0.05	0.02	94.6 %
S_6	4.39	0.12	

5. DEVELOPMENT OF SOUND QUALITY IMPROVEMENT OF DOOR LATCH

5.1 Noise source analysis

Sound field visualization was implemented using acoustic camera to identify the noise source in a condition of real car. For experimental convenience, visualization was done by installing whole door module to self-manufactured zig. MEMS microphone type 30 channel, spiral array caemra was used for sound field visualization.

Figure 8 shows the sound field of the instant moment that door latch operates. Bolting point of door latch and nobe were found to be prime noise source. Impact sound of door latch is direct radiation noise rather than structural-borne noise because main noise is occuring at the point of impact happens.

Figure 8 – Results of sound field visualization of door latch operating moment

Though this research solve the problem by controlling force of door latch because it was focusing on improvement of assay, improvement of nobe is inevitable for further research.

5.2 Improvement of impact sound

We made a conclusion that most efficient way to improve the sound quality of door latch is to reduce the impact sound of assay because operation sound of door latch directly radiates to air. Thus, to reduce the impact sound of door latch, high viscosity grease was applied to inside of door latch. High viscosity grease reduce the impact force at the moment of impact and stiffness of impact area so that excitation frequency range of impact sound would be narrower than before.

To verify the effect of sound quality improvement, improved door latch was applied to real car and operation sound was recorded using same method referred earlier. Effect of sound quality improvement was not confirmed by conducting jury evaluation but substituting objective metrics into sound quality index. It is coincide to purpose of research which is simplification of sound quality evaluation.

Table 4 and 5 show the main sound quality metrics and sound quality index results of improved door latch's 'opening' motion and 'closing' motion operation sound. For the case of 'closing' motion, L_1 reduced degree of 6.2 and S_6 reduced degree of 0.11. Because of reduction of L1 and S6, sound quality index was increased degree of 2.15 which is quite large in a total scale of 10. For the case of 'opening' motion, L_1 reduced degree of 4.7 and S6 reduced degree of 0.06. Sound quality index was increased degree of 1.26 which is not large as 'closing' motion but it could also evaluated to be outstanding development.

Table 4 – Sound measurement results of optimized door latch in 'Locking' sound

	Before optimizing	After optimizing
L_1	83.4	77.2
S_6	1.00	0.89
SQI	1.36	3.51

Table 5 – Sound measurement results of optimized door latch in ‘Unlocking’ sound

	Before optimizing	After optimizing
L_1	83.4	77.2
S_6	1.00	0.89
SQI	1.36	3.51

6. CONCLUSIONS

Even though the ‘locking’ and ‘unlocking’ sounds of a door latch have different characteristics, some degree of correlations were found in terms of customers’ preferences. For both locking and unlocking sounds within a door latch module, it is found that the smaller and sharper the sound, the more luxury the quality. Also, it is found that the sharpness of the sound plays a bigger role in deciding the quality of the door latch operating sound. In this study, it is confirmed that the door latch sound is mostly emitted by air-borne noise, which directly radiates to the receiver. Thus, reducing the amplitude of the latch is primarily tackled rather than optimizing the path, and the index that was developed in this study was used to assess the sound quality improvement of the optimized door latch.

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