

Psychoacoustic Evaluation Model on the Luxury of Sound Quality in Vehicle Interior Noise

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Abstract: This paper studied the comprehensive evaluation index of sensory luxury of Sound Quality in Vehicle interior noise. The relationship between it and psychoacoustic parameters under different conditions was studied. Four types of vehicle real-time noises were recorded at several running speeds and later were subjectively evaluated in the testing room by semantic subdivided method. According to the subjective test and evaluation, the psychoacoustic objective quantificational model was built using correlation analysis and multi-dimensional linear regression analysis. The results indicated that: the luxury of vehicle interior noise showed good correlation with loudness and sharpness. The luxury increased as loudness or sharpness decreased, but it decreased as speed increased.

Keywords: Luxury, psychoacoustic, multiple regression, objective quantificational model, sound quality, vehicle

INTRODUCTION

Some research have discovered that A weighted level standard had not thoroughly considered the acoustics quality characteristic of vehicle noise and couldn't reflect the automobile noise comprehensively to human's harassment. Sound quality (Matthias and Michael, 1999) can reflect the subjective sensation of human as evaluation subject under specific environment, may be quantitatively described accurately with psychological acoustics objective parameters measured and computed (Bodden *et al.* 1998). These parameters considered human psychology response and the noise sensation characteristic could reflect the subjective feeling difference caused by different noise signals. The sound quality evaluation model is very important for the evaluation, analysis and control of modern vehicle noise. Yinhan *et al.* (2010) and Kousuke and Yoshida (2003a) had focused on the evaluation method. Naihua *et al.* (2008) found effective parameters and Dongxing (2007) and Dengfeng *et al.* (2006) investigated the subjective evaluation measures. Choe (2001) had studied the comprehensive evaluation index of Sensory Pleasantness related to psychoacoustic parameters. Fastl (2005) got the quantificational model on another comprehensive evaluation index of annoyance. Kousuke and Yoshida (2003b) studied the luxury and motile of sound quality more deeply. He made the formula between sound quality and some psycho-acoustical parameters. In this study, luxury was

examined as a comprehensive evaluation index in relation to four psycho-acoustical parameters.

The experiment to vehicle interior noise was carried out at different speed for different vehicle in this study. Luxury of sound quality was subjectively evaluated by means of semantic differential to the test signals and four psychoacoustics parameters of loudness, sharpness, fluctuation and roughness were calculated at the same time. These parameters synthetically considered human psychology response mechanism and the noise sensation characteristics. They also could reflect the subjective feeling difference caused by different noise signals. Based on the research of the relationship between objective evaluation parameters and subjective evaluation results, an objective quantitative evaluation model was established and verified finally.

EXPERIMENTS

In the experiments, we gained the data using the products of German Head Acoustics Corporation. First, real binaural sound signals were recorded by binaural headsets -SQuadriga which has mobile 4-channel USB-fronted with internal flash memory. Then, software of Artemis 7.0 and playback system to playback the samples with high fidelity by special monitoring earphone-Sennheiser HD600 were also used. The equipments of experiment were shown as Fig. 1.

The sound signals were acquired during the test with 4 middle-grade cars under three speeds of idling,



Fig. 1: Equipments of experiment

Table 1: Seven-level semantic differential in the experiment

Luxury	Rating scale
Very vile	1
Comparatively vile	2
A little vile	3
Common	4
A little slap-up	5
Comparatively slap-up	6
Very slap-up	7

40 km/h and 80 km/h. The experiment acquired 12 noise samples altogether. The length of each sample was 10 sec and was 5 sec after editing.

The jury divides into two groups. One group was the professional group which composed by 10 people including 8 men and 2 women aged from 22 to 30 years old. They all were graduate students in vehicle engineering working on vehicle noise control. They were quite familiar to acoustics concepts and had been trained on the noise listening. Other group was the ordinary group which composed of 14 people including 10 men and 4 women aged from 20 to 42 years old. Most of them were students of vehicle specialty. There were 3 drivers in this group who had driven over 10 years. They had rich driving or riding experience and were familiar to vehicle noise. 12 noise samples were evaluated subjectively with semantic differential by 7 level appraisal rating scale (Zwicker and Fastl, 1999) which shown in Table 1.

RESULTS

Subjective evaluation results: In order to choose reasonable date and judge the validity of dates, statistical analysis for experiment date after subjective evaluation must be made. Firstly, the dates were checked up. The reliability of date were judged through checking up the correlation of the results from different appraisers. Firstly, the Kendall's Harmonious Coefficient (Huixin, 2005) was calculated. It is a common coefficient in the checkout of experiment date which can express the consensus degree among several variables. Kendall's Harmonious Coefficient performances on the scale of "0" to "1". If it is "0", it means no correlation among all the evaluation results. On the contrary, "1" means all the evaluation results

Table 2: Kendall's Harmonious coefficient of samples

	Before eliminating	After eliminating
All	0.729	0.794
Professional	0.847	0.891
Ordinary	0.636	0.768

Table 3: Psychoacoustics parameters of all samples

Samples	Loudness (sone)	Sharpness (acum)	Fluctuation (vacil)	Roughness (asper)
A1	7.32	0.805	0.435	1.254
A2	8.63	0.742	0.492	1.039
A3	7.98	0.849	0.419	0.941
A4	12.45	0.924	0.534	0.841
B1	12.18	0.948	0.276	0.92
B2	11.57	0.981	0.259	0.962
B3	13.87	1.027	0.194	1.235
B4	20.15	1.139	0.218	1.647
C1	21.89	1.158	0.257	1.395
C2	22.36	1.197	0.272	1.671
C3	23.91	1.256	0.248	1.598
C4	25.16	1.294	0.281	1.692

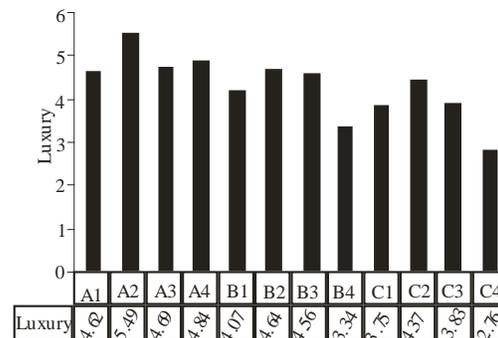


Fig. 2: Luxury of all the samples

present very good coherence. The evaluation results are considered efficacious if Kendall's Harmonious Coefficient is above 0.75 under the condition of a great deal of appraisers according to Kendall (1955). Then, after eliminating instability date, the Kendall's Harmonious Coefficient was recalculated which shown in Table 2. In Table 2, the Kendall's Harmonious Coefficient after eliminating instability dates had been better improved and they indicated the date were effective.

Last, the results of all the appraisers were listed such as Fig. 2. In Fig. 2, "A" presents the samples acquired at idle speed, the "B" in the speed of 40km/h and the "C" in 80 km/h; and 1, 2, 3, 4 expresses four different test cars respectively.

As Fig. 2 shown, the luxury score of the "A2" was the highest under the idle speed and it decreased as speed increased.

Results of objective evaluation parameters: Four psychoacoustics parameters of loudness, sharpness, fluctuation and roughness of noise samples were calculated with the Artemis 7.0 software. The results were listed in Table 3.

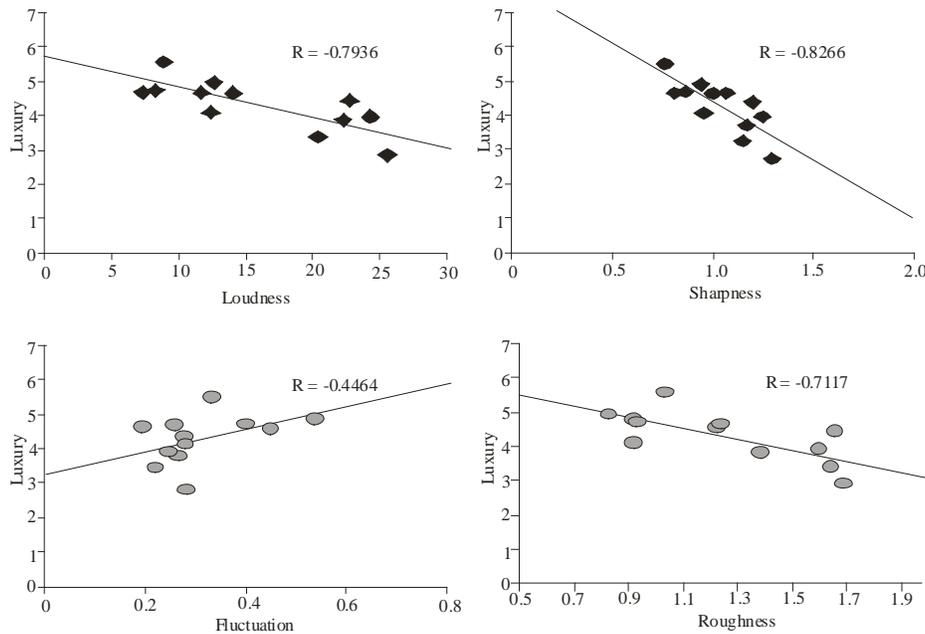


Fig. 3: Scatter and linear relation between luxury and psycho-acoustical parameters

DISCUSSION

Linear correlation analysis: Firstly, the linear correlation and correlation coefficient between the luxury and the mentioned above four psychoacoustics parameters were calculated in Fig. 3.

In Fig. 3, it was clearly seen that the sharpness showed the high correlation with luxury, which coefficient of correlation is -0.8266. That is, as larger the sharpness became, the worse luxury was judged. So as loudness and roughness, their coefficients of correlation are -0.7936 and -0.7117 respectively. However, there was only a little correlation between luxury and fluctuation. Its correlation coefficient was 0.4464 and its scattered points were messy. So, it was thought no direct linear correlation with luxury.

In order to express the relation among these parameters more definitely, the Pearson correlation coefficient of those were shown in Table 4. In Table 4* indicated the date by testing reliability under 0.05. Table 4 showed that loudness, sharpness and roughness had strong correlation with luxury, their Pearson correlation coefficient was above 0.7. Only fluctuation presented relatively weak correlation with luxury. It can be seen the luxury mainly affected by loudness, sharpness and roughness. The date in Table 4 indicated that the linear correlation analysis before were correct.

Psychoacoustic objective quantificational model: The multi-dimensional linear regression can be used to

Table 4: Pearson correlation coefficient and two-tailed test of all parameters

	Loudness	Sharpness	Fluctuation	Roughness
Correlation coefficient	-0.793*	-0.827*	0.446	-0.712*
Two-tailed test	0.002	0.001	0.146	0.091

study the correlation among the variables. This statistical method supposes that there is a linear relation between dependent and independent variables and the test data of dependent and independent variables are fitted with certain linear regressive model. Then, in the experiment a regressive equation could be obtained through above parameters. So the correlation among the variables can be analyzed with the regressive equation (Wolfgang and Leopold, 2007).

According to the theory mentioned above and sound quality properties, the sound quality objective parameterization model can be established as Eq. (1):

$$Y_{hi} = \beta_0 + \beta_1 X_{Li} + \beta_2 X_{Si} + \beta_3 X_{Fi} + \beta_4 X_{Ri} \quad (1)$$

This was one order model including four dependent variables, while, Y_{hi} means luxury of sound quality; $\beta_0 \sim \beta_4$ were parameters which needed to be determined; X_{Li} , X_{Si} , X_{Fi} and X_{Ri} meant loudness, sharpness, fluctuation and roughness of each noise sample respectively.

Each psychoacoustics parameter is not completely irrelevant, but is restrained mutually by some kind of recessive relations. The model with more accuracy

Table 5: Results of regression analysis of luxury

	Correlation coefficient	S.E.	Standard coefficient	Credible probability
Constant	9.022	2.920		0.018
Loudness	-0.546	0.115	0.529	0.641
Sharpness	-4.755	3.898	-1.172	0.710
Fluctuation	-0.463	1.921	-0.062	0.416
Roughness	0.486	0.906	0.215	0.308

could be established by increasing model order by means of some method (Michael *et al.*, 2004). Following method was used in this study. First, based on the calculating model of each psychoacoustics parameters, complex correlation coefficient R could be found between each parameter and the subjective appraisal results. Then each parameter was ranked according to the value of R^2 . At last the parameters could be computed after eliminating the parameter whose complex correlation coefficient was extremely small.

Actually, the data's testing matrix of independent variables and the dependent variables could be known, but the regressive coefficient was unknown. So the statistical problem became to estimate the regressive coefficient according to the known observed data matrix and then verified the estimated value statistically. This procedure was repeated until the regressive coefficients which had the smallest error. This procedure could be generally done by a computer with the functional software of regressive analysis, such as SPSS (Statistical Package for the Social Sciences) (Jianqiong *et al.*, 2006) in the study.

Inputting the Eq. (1) and the data in Fig. 2 and Table 3 into the software SPSS, the computed results were obtained in Table 5.

The parameters whose credible probabilities above 0.5 could be selected. According to the results of 5, the loudness and sharpness could be selected because their credible probabilities were 0.641 and 0.710. But, the fluctuation and roughness were deleted for their credible probabilities not reaching 0.5. Finally, the psychoacoustics objective quantitative model with subjective evaluation parameters was obtained. It can be shown in Eq. (2):

$$Y_h = -0.054X_L - 4.755X_s + 9.022 \quad (2)$$

In Eq. (2), X_L and X_s present loudness and sharpness.

From the analysis on the data with the standard error, the residual error and the credible probability, it could be found that the accuracy of the experimental results were not satisfactory completely and the precision of coefficients for the sound quality objective

quantitative model were needed to be verified further by experiment. The reason for these might be that the appraisers' experience were insufficient, the quantity of samples and appraisers were also not enough.

CONCLUSION

Thus, due to the experiment date, it could be seen that the luxury of the same car decreased as the speed increase. The analysis results indicated that the influence of loudness and sharpness to luxury were obvious among four psychoacoustics parameters, while the influence of fluctuation and roughness were not obvious.

The subjective evaluation model of sound quality with psychoacoustics parameters had been established based on the subjective appraisal experiment and the data analysis. Loudness and sharpness had high positive correlative relation, which meant that the bigger loudness/sharpness was, the worse luxury was.

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