

Study of Interior Sound Preferences at Acceleration

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ABSTRACT

This paper describes car interior sound preferences in general public. Subjective evaluation experiments were performed in Japan, Germany and the United States to investigate the interior sound preferences. Two hundred subjects in each country (600 total) participated in the experiment. As a result, four kinds of preferences were found. A sound preference evaluation system was developed to calculate numeric preference values based on sound stimuli recorded using an artificial head microphone.

Furthermore, subjects' characteristics in each kind of preference were clarified through questionnaires. The results showed that women, older people and people not interested in cars preferred quiet sound, while men, younger people, and people who like cars preferred powerful sound.

1. Introduction

Various researches of sound quality evaluation techniques were conducted for enhancing sound quality in vehicle interiors. As a result of these researches, various metrics have been proposed for auditory stimuli, including loudness and fluctuation intensity⁽¹⁾, and for complex sensations, luxuriousness and sportiness^{(2),(3)}, allowing for a quantitative evaluation of sensations experienced in response to sound. Studies have indicated that even when the sensation experienced is identical, preferences with regard to those sensations can be entirely different⁽³⁾. Also, there is a lack of detailed data on the types of sound preferred by different users.

In the research discussed in this paper, subjective evaluation experiments of interior sound preferences were conducted in Japan, Germany and the United States. Test subjects were asked to fill out a questionnaire on personal information: age, gender, etc. The results were analyzed statistically. Objective numerical values were

calculated for the degree of preference users had for measured interior sounds and the preferences were then classified based on the users' attributes, or personal data.

This paper discusses the results of the analysis, the method used to calculate the degree of user preference, and gives an overview of the preference evaluation system based on this method.

2. Subjective Evaluation Experiments

In the subjective evaluation experiments, interior sound recorded during acceleration was played back via headphones to determine subject preferences.

2.1. Sounds Presented to Subjects

Binaural recordings of interior sounds measured during acceleration in 18 vehicle types marketed in Japan, Europe and the

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Table 1 Number of subjects

Sound type	Japanese	German	American
Low engine speed	206	207	202
Middle engine speed	206	207	202
High engine speed	206	207	202

United States were made using artificial head microphones and played for test subjects. Twelve sound types each were selected from low engine speeds (approximately 1 000-3 000 rpm), medium engine speeds (approximately 3 000-5 000 rpm) and high engine speeds (approximately 5 000-7 000 rpm). These recordings were edited down to 2 seconds. An exponential function weighting procedure was used for 0.2 seconds at each end of the signal to control transient sound bits and the recordings were converted into digital audio files so that they could be played back on a computer.

2.2. Test Apparatus

The test apparatus consisted of a computer and a binaural playback system, as shown in Fig. 1. The sounds were played back using an original software program. A maximum of four subjects were able to listen to the sounds at the same time and provide subjective evaluations.

2.3. Test Subjects

The average age and gender of the test subjects were approximately equal to the average age and gender of licensed drivers in the countries in which the tests were conducted. It was predicted that a diverse range of preferences would be indicated, thus making a large pool of test subjects, which was essential to obtain statistically significant results. Approximately 200 test subjects were selected from Japan, Germany and the United States (for a total of about 600). Table 1 shows the number of test subjects organized according to the range of engine speed sounds presented to them in tests.

2.4. Test Method

Sheffe's paired comparison method⁽⁴⁾ was used to provide highly accurate assessments with respect to evaluations and enables the degree of assessment to be determined.



Fig. 1 Experimental apparatus

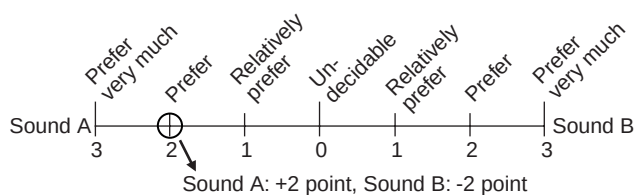


Fig. 2 Answer sheet in Sheffe's paired comparison method

Table 2 Preference value in each comparison

Sound number	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12
No.1		1	1	2	-1	1	-1	-1	1	2	1	1
No.2	-1		-1	2	-2	-2	-2	-2	-1	-2	-2	1
No.3	-1	1		2	-2	-2	-1	-2	-1	-1	-2	1
No.4	-2	-2	-2		-2	-3	-2	-3	-2	-2	-2	-3
No.5	1	2	2	2		-1	1	-2	1	1	2	1
No.6	-1	2	2	3	1		-1	-1	1	-1	2	2
No.7	-1	2	1	2	-1	1		-2	-1	-1	2	1
No.8	1	2	2	3	2	1	2		1	2	2	1
No.9	-1	1	1	2	-1	-1	1	-1		1	2	1
No.10	-2	2	1	2	-1	1	1	-2	-1		0	1
No.11	-1	2	2	2	-2	-2	-2	-2	-2	0		2
No.12	-1	-1	-1	3	-1	-2	-1	-1	-1	-1	-2	
Ave.	-0.6	1.1	0.7	2.3	-0.9	-0.8	-0.5	-1.7	-0.5	-0.2	0.3	0.8

Pairs of sounds were played for subjects over headphones. Each sound pair was repeated twice and the subjects were asked to select their preferred sound and mark a degree of preference on an answer sheet using the scale shown in Fig. 2. This procedure was repeated 66 times for each engine speed range, in random order, for a total of 198 times for each test subject. Approximately 200 subjects were tested in each country, with up to four subjects tested at one time; the tests were therefore conducted approximately 50 times in each country. To reduce the effect of presentation order on the evaluations, the order of the pairs of sounds was changed for each test.

3. Quantification of Sound Preferences

Multivariate analysis was applied to the results of the subjective evaluation experiments for each engine speed range to quantify the test subjects' preferences, which were then classified in relation to specific types of sound and evaluated on the basis of objective numerical values.

3.1. Quantification of Sound Preferences in the Low Engine Speed Range

The results for each test subject were used to produce numerical figures representing their relative degree of preference, as shown in Table 2. Average values for each type of sound presented were calculated using these figures and assigned as numerical representations of the degree of preference expressed by the test subject. Below, these values are termed subjective preference values (SPV).

Figure 3 shows SPVs for all 615 Japanese, German and U.S. test subjects, plotted for the 12 types of sound presented in the tests.

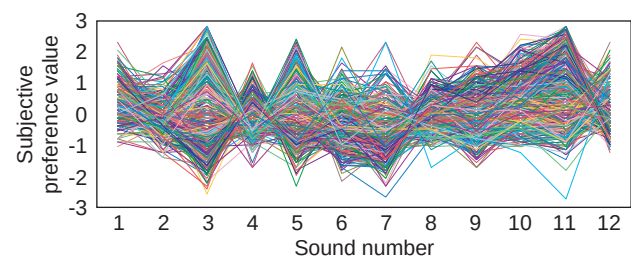


Fig. 3 Preference in each subject

These results indicate that there was significant diversity in the test subjects' individual preferences. Particularly in relation to sounds 3, 7 and 11, for which some subjects indicated an extremely strong preference, while others exhibited an equally strong negative reaction: a significant contrast. User preferences are therefore not uniform. A number of different types of preference can be considered to exist. To elucidate these preference types, cluster analysis⁽⁵⁾ was used to classify test subjects into groups according to the order of their preferences.

As Fig. 4 shows, three clusters were generated at the low engine speed range. This indicates that criteria for preferences do not differ entirely for each individual. Preferences fall mainly into three groups and most individuals can be represented in one of these three groups.

As Fig. 5 shows, Cluster 1 contains the highest proportion of test subjects, at approximately 70%. This indicates that if the sound preferred by the test subjects in Cluster 1 was produced by an actual vehicle, about 70% of vehicle purchasers would like it. Note that statistically insignificant test subjects were included in the "Other" category.

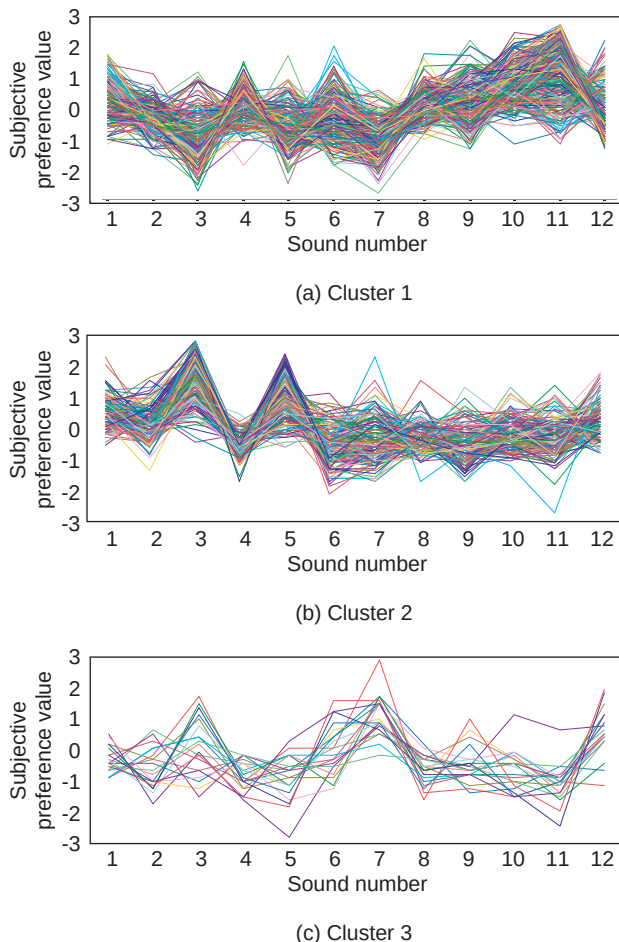


Fig. 4 Subjective preference value in each cluster

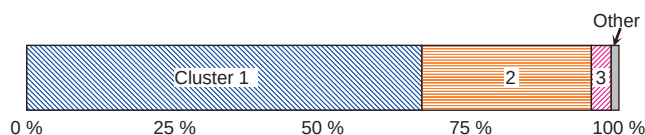


Fig. 5 Preference groupings at low engine speed

Next, multiple regression analysis⁽⁵⁾ was conducted to clarify the types of sound preferred by the test subjects in each cluster. The average subjective preference values of the test subjects in each cluster were employed as dependent variables in the analysis. Values for Honda's sound quality evaluation metrics⁽³⁾ (luxuriousness, smoothness, loudness, sportiness, aliveness and power) were calculated from actual measurements taken using an artificial head microphone and used as the independent variables.

Multiple regression analyses were conducted for each cluster. The results for Cluster 1 are shown in Eq. (1), for Cluster 2 in Eq. (2), and for Cluster 3 in Eq. (3). The terms on the right side of the equations are selected to ensure that the left sides maintain a high degree of correlation with the subjective preferences, which function as dependent variables. The left sides of these equations represent objective preferences, which are termed objective preference values (OPV) below. Each of the terms on the right side of the equations describes the sound characteristics to which the OPVs relate.

$$\begin{aligned} \text{OPV 1 (Cluster 1)} \\ = -5.2 \times \text{Loudness} + 0.4 \times \text{Smoothness} - 1.3 \end{aligned} \quad (1)$$

$$\begin{aligned} \text{OPV 2 (Cluster 2)} \\ = -3.2 \times \text{Loudness} + 1.3 \times \text{Power} - 0.4 \times \text{Aliveness} - 0.7 \end{aligned} \quad (2)$$

$$\begin{aligned} \text{OPV 3 (Cluster 3)} \\ = 3.5 \times \text{Loudness} + 0.8 \end{aligned} \quad (3)$$

The results produced by Eqs. (1)-(3) show that test subjects in Cluster 1 preferred a "quiet, smooth sound," while subjects in Cluster 2 preferred a sound that was "powerful rather than alive," and subjects in Cluster 3 preferred a "loud sound." Figure 6 shows a scatter diagram of the SPVs obtained from the results of the subjective evaluation experiments and the OPVs calculated using Eqs. (1)-(3), and the correlation coefficients between them. High correlation coefficients were obtained for all of the clusters, indicating that the SPVs had been successfully quantified.

3.2. Quantification of Sound Preferences in the Medium Engine Speed Range

In the same way, preferences in the medium engine speed range were quantified by first calculating subjective preference values for each test subject, then conducting cluster and multiple regression analyses.

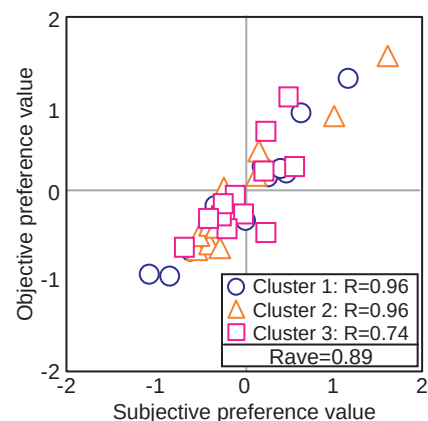


Fig. 6 Correlation between subjective and objective preference values at low engine speed

Cluster analyses of medium engine speed sound preferences generated four cluster types. The ratio of subjects in each cluster is shown in Fig. 7.

The results differ from the results obtained for the low engine speed range. Cluster 1 has the highest ratio, at around 50%, while Cluster 2 also has a high ratio at 40%.

As was the case for the low engine speed range, multiple regression analysis was conducted for each cluster. The results for Clusters 1 through 4 are shown as Eqs. (4) through (7), respectively.

$$\begin{aligned} \text{OPV 1 (Cluster 1)} \\ = -3.4 \times \text{Loudness} + 1.2 \times \text{Smoothness} + 0.1 \end{aligned} \quad (4)$$

$$\begin{aligned} \text{OPV 2 (Cluster 2)} \\ = -1.1 \times \text{Loudness} + 0.8 \times \text{Power} - 0.8 \times \text{Aliveness} \end{aligned} \quad (5)$$

$$\begin{aligned} \text{OPV 3 (Cluster 3)} \\ = 1.1 \times \text{Loudness} + 0.5 \times \text{Aliveness} - 0.3 \end{aligned} \quad (6)$$

$$\begin{aligned} \text{OPV 4 (Cluster 4)} \\ = -3.9 \times \text{Loudness} + 0.6 \times \text{Aliveness} \end{aligned} \quad (7)$$

The results show that test subjects in Cluster 1 preferred a “quiet, smooth sound,” while subjects in Cluster 2 preferred a “powerful rather than alive sound,” those in Cluster 3 preferred a “loud, alive sound” and those in cluster 4 preferred a “quiet, alive sound.” As Fig. 8 shows, high correlation coefficients between the SPVs and OPVs were also obtained for each cluster in the medium engine speed range.

3.3. Quantification of Sound Preferences in the High Engine Speed Range

As with the low and medium engine speed ranges, preferences in the high engine speed range were quantified by first calculating subjective preference values for each test subject, then conducting

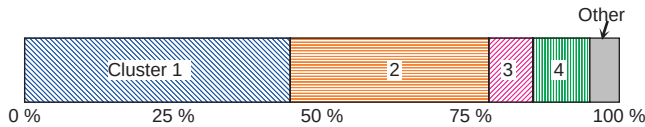


Fig. 7 Preference groupings at middle engine speed

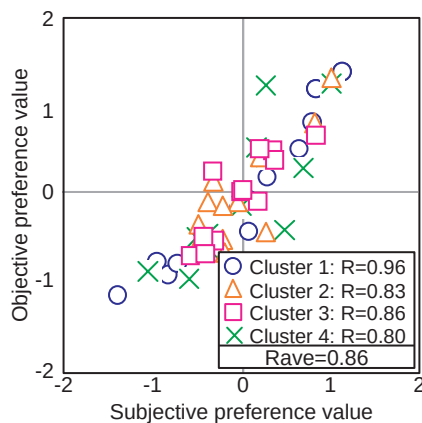


Fig. 8 Correlation between subjective and objective preference values at middle engine speed

cluster and multiple regression analyses.

Cluster analysis of the high engine speed range produced four clusters, the same as for the medium engine speed range. Figure 9 shows the ratio of test subjects in these clusters.

As with the other two engine speed ranges, multiple regression analysis was conducted for each cluster. The results for Clusters 1 through 4 are shown as Eqs. (8) through (11), respectively.

$$\begin{aligned} \text{OPV 1 (Cluster 1)} \\ = -2.9 \times \text{Loudness} + 1.0 \times \text{Smoothness} + 1.7 \end{aligned} \quad (8)$$

$$\begin{aligned} \text{OPV 2 (Cluster 2)} \\ = -5.3 \times \text{Loudness} + 2.1 \times \text{Power} - 0.4 \times \text{Aliveness} - 0.2 \end{aligned} \quad (9)$$

$$\begin{aligned} \text{OPV 3 (Cluster 3)} \\ = 2.5 \times \text{Loudness} - 1.2 \end{aligned} \quad (10)$$

$$\begin{aligned} \text{OPV 4 (Cluster 4)} \\ = -2.3 \times \text{Loudness} + 0.4 \times \text{Smoothness} + 0.8 \end{aligned} \quad (11)$$

The results show that subjects in Cluster 1 preferred a “quiet, smooth sound,” subjects in Cluster 2 preferred a “powerful rather than alive sound,” subjects in Cluster 3 preferred a “loud sound” and subjects in Cluster 4 preferred a “quiet, alive sound.” As Fig. 10 shows, high correlation coefficients were obtained between the SPVs and OPVs in each cluster in the high engine speed range.

As discussed above, the analyses conducted indicated three types of preference for interior sound during acceleration at low engine speeds, and four types each for interior sound during acceleration at medium and high engine speeds. The authors theorized that the reason the preference for a “quiet, alive sound” was quantified for the medium and high engine speed ranges, but not for the low engine speed range was that the high-order component, which is essential for the sensation of aliveness, was small at low engine speeds.

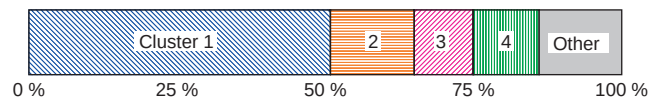


Fig. 9 Preference groupings at high engine speed

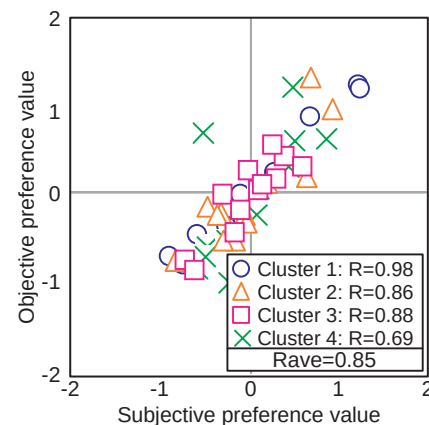


Fig. 10 Correlation between subjective and objective preference values at high engine speed

4. Questionnaire Survey of Test Subjects' Attributes

The subjects who participated in the subjective evaluation experiments were also asked to fill out a questionnaire survey to establish causal relationships between their preferences and their attributes. The questions in the survey concerned the following five areas:

- (1) Personal information
Gender, age, occupation, etc.
- (2) Car-related information
Type of car owned by the subject, level of interest in cars, criteria for choosing cars, etc.
- (3) Flexibility of opinion
Interest in new products, interest in meeting a wide range of people, etc.
- (4) Lifestyle
Degree of emphasis on career, desire to live in the country, etc.
- (5) Hobbies, leisure activities
Travel, sports, etc.

To determine what kind of person preferred what type of sound, the changes in the ratio of subjects in each cluster, i.e. the distribution ratio of subject preferences (termed the preference distribution ratio below) for each attribute was analyzed.

Figure 11 shows the preference distribution ratio for all test subjects before dividing them into attribute groupings. Out of all the engine speed ranges, Cluster 1 has the highest ratio, followed by Cluster 2.

Next, we focused on the interesting question of whether the preference distribution ratio differed between Japan, Germany and the United States, given certain differences in the automotive cultures of the countries. Figure 12 shows the results of the analysis by country. While there are some minor differences between the countries, the results show general similarities.

The rest of this section will analyze the preference distribution ratio with respect to a variety of test subject attributes, particularly in cases in which there is a comparatively high degree of difference in the preference ratio distribution for all test subjects.

Figure 13 shows the preference distribution ratio for each age group. These results indicate that the higher the age of the group, the more the subjects preferred a quiet, smooth sound, and the lower the age of the group, the more the subjects preferred a powerful rather than alive sound. A particularly high number of test subjects under the age of thirty preferred a powerful rather than alive sound in the medium engine speed range.

Figure 14 shows the preference distribution ratio by gender. These results show that a higher number of men preferred a powerful rather than alive sound, while a higher number of women preferred a quiet, smooth sound. A higher proportion of men than women preferred a loud, alive sound.

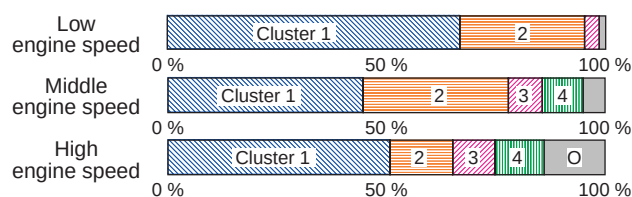


Fig. 11 Preference groupings among all subjects

Figure 15 shows preference organized by degree of interest in cars. These results show that the largest number of people who were interested in cars preferred a powerful rather than alive sound, while the largest number of people who were uninterested in cars preferred a quiet, smooth sound.

In total, the results obtained indicated that larger numbers of older people and women preferred a quiet, smooth sound, while larger numbers of younger people, men and those with an interest in cars preferred a powerful rather than alive sound. The results also indicated that a larger number of men than women preferred a loud, alive sound.

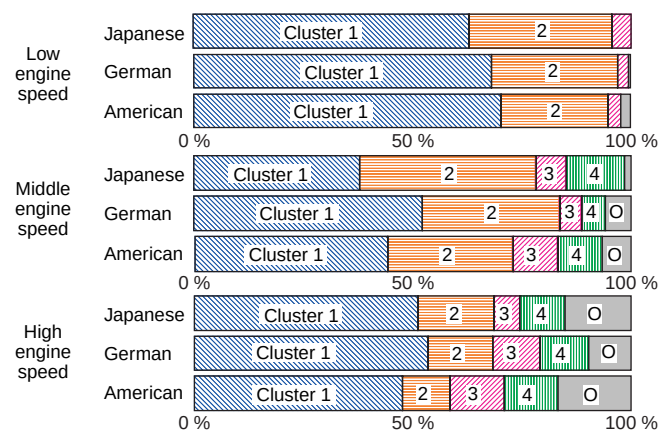


Fig. 12 Preference groupings for each nationality

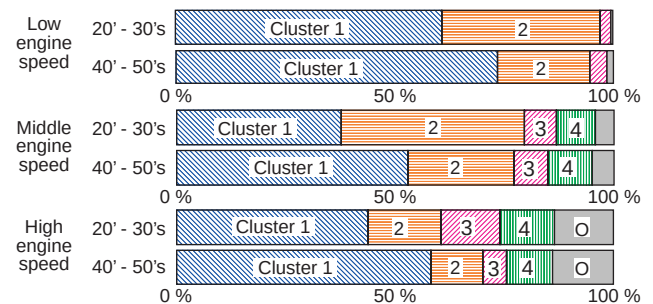


Fig. 13 Preference groupings for each generation

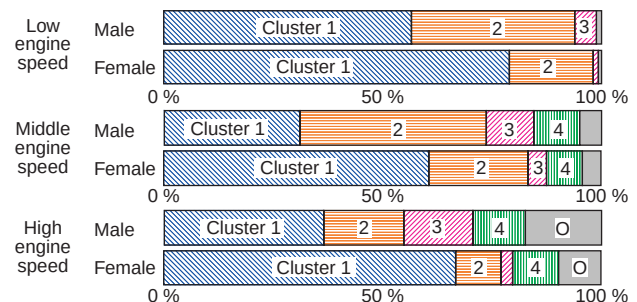


Fig. 14 Preference groupings for each gender

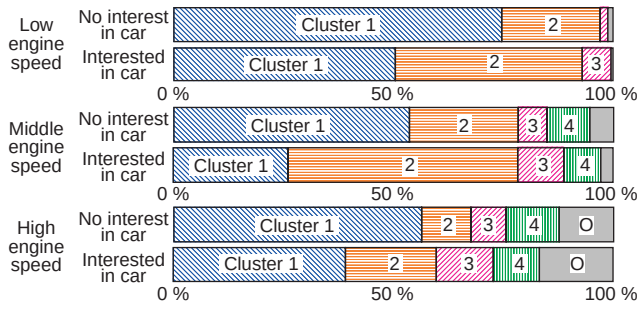


Fig. 15 Preference groupings depending on subject's car interest

5. Development of a System for Evaluation of Objective Preference Value

If the users targeted by a vehicle development concept can be roughly defined, the method discussed in this paper can be used to select the objective preferences that should be focused on in the development process, and determine the makeup of the sound those preferences relate to. A system for evaluating objective preference values was developed to enable efficient evaluations during the product development process. The system numerically processes

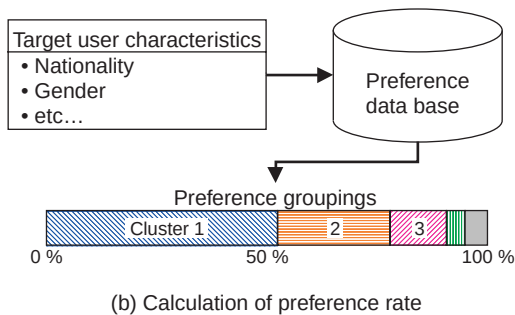
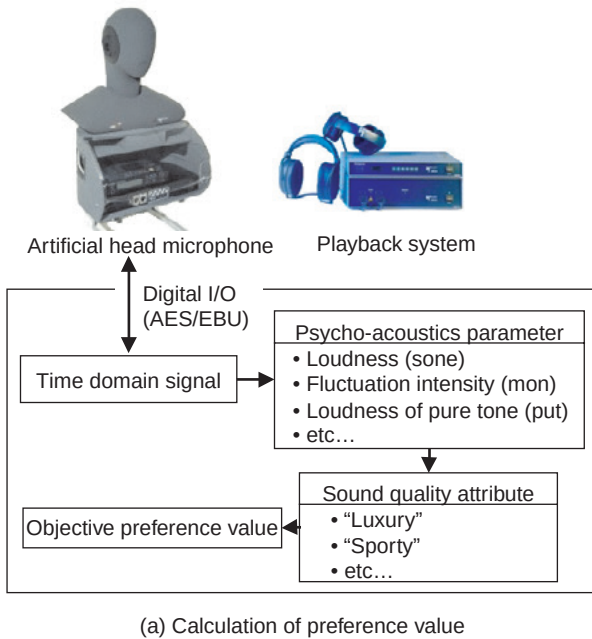


Fig. 16 Preference evaluation system

sound pressure signals recorded by an artificial head microphone to generate metrics for auditory stimuli, including loudness and fluctuation intensity, and for complex sound quality evaluation, including luxuriousness and smoothness. These values allow preferences to be calculated in the low, medium and high engine speed ranges. Figure 16 shows an outline of the system.

As an example, Fig. 17 shows the results of an analysis of the interior sound at full throttle acceleration in the medium engine speed range for two vehicles, A and B, while Fig. 18 shows the preference ratio when the target users are Japanese in their 20s and 30s with an interest in cars.

Based on these results, car B was judged preferable by the larger number of users because of its powerful rather than alive sound.

As this indicates, the system enables objective preference values to be calculated from measured sounds, and simplifies the assessment of whether target users will like the sound.

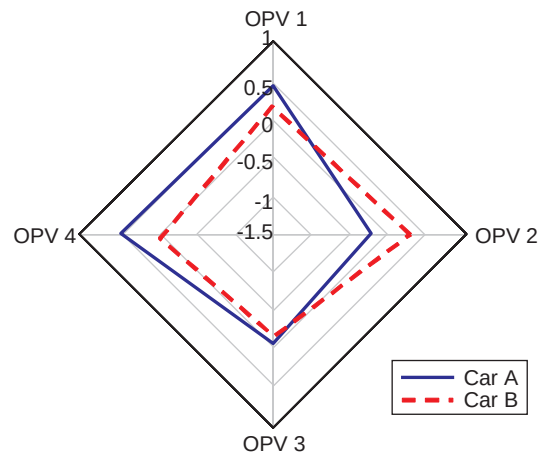


Fig. 17 Calculated preference value

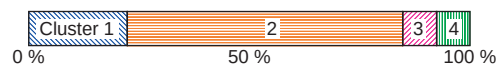


Fig. 18 Preference groupings in selected subject's characteristics

6. Conclusion

The research project discussed in this paper conducted subjective evaluation experiments and questionnaire surveys with the participation of approximately 600 test subjects in Japan, Germany and the United States. The following significant points were determined in this project:

- (1) The research determined three types of interior sound preferences in the low engine speed range, and four types each in the medium and high engine speed ranges.
- (2) It was possible to express the subjective preferences that had been determined as objective sound preference values.
- (3) The attributes of the test subjects, in particular, gender, age and degree of interest in cars, were shown to be factors that broadly divided the subjects' sound preferences.

- (4) A system enabling the evaluation of objective preference values was developed to assist in clarifying measures to modify sound to attain the sound quality preferred by target users.

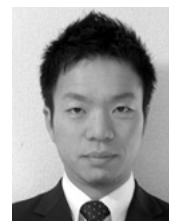
References

- (1) Noumura, K., Okada, Y.: Sound Quality Evaluation Technique of Vehicle in Consideration of Auditory Characteristic, HONDA R&D Technical Review, Vol. 9, p. 131-139
- (2) Ishii, Y., Yamashita, T., Brandl, F. K., Thomann, S., Biermayer, W.: Development of a New Software for Objective Evaluation of Interior Sound of Sports Cars, Honda R&D Technical Review, Vol. 13, No. 1, p. 131-138
- (3) Noumura, K., Yoshida, J.: Quantification of Luxury and Sporty Car Interior Sounds Perceived by the General Public in Different Markets, Honda R&D Technical Review, Vol. 14, No. 1, p. 237-246
- (4) Nanba, S., Kuwano, S.: Method of Psychological Measurement for Hearing Research, CORONA PUBLISHING CO., LTD., p. 221 (1998)
- (5) Ishimura, S.: Sugu Wakaru Tahenryou Kaiseki, Tokyo tosho, p. 201 (1992) (in Japanese)

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