

Quantification of Luxury and Sporty Car Interior Sounds Perceived by the General Public in Different Markets

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ABSTRACT

Sensory evaluation tests were conducted to clarify differences in Japanese, German, and American perception of car interior sounds. The results of statistical analysis indicate that perceptions can be classified under two major categories: Luxury and Sporty, and that car interior sounds can be represented by these two axes. Further analysis of the sensory evaluation tests showed that sound preferences could also be described by these same categories. It is seen that even people with different preferences could have the same perception of luxury and sporty sounds. By country, a sporty acceleration sound was most preferred by Japanese, American, and German subjects, respectively. An application was developed that is capable of computing objective values for luxury and sporty sounds.

1. Introduction

To guarantee overall automobile marketability, improvements to sound quality are essential. In order to achieve these improvements, many psychoacoustic metrics have developed to quantify human hearing as an objective index. There have been a number of proposals for psychoacoustic metrics around the world, ranging from attributes that express simple auditory stimulus levels, such as loudness or roughness, to complex attributes, such as annoyance or sportiness⁽¹⁾. However, as an index, these are usually multiple choice, so giving due consideration to market differences and driving condition differences, it is difficult to incorporate everything. Therefore, a rational, easy-to-use index is desirable.

In this research project, sensory inspections were implemented, with the subjects being ordinary Japanese, German, and American people. An ordinary person's perceptions about sounds inside cars were clarified through

statistical analysis. Objective evaluation attributes were then determined, that can be applied universally, under different driving conditions including acceleration, cruising, and idling, etc. The goal was to develop a sound evaluation system that realizes this calculation algorithm. In addition, mention is also made of which sound qualities are preferred by the people in each country, by making clear the links between the various attributes and sound preferences.

2. Sensory Evaluations

2.1. Subjects

The people involved in the evaluation were men and women from each of the countries involved, ordinary people in their 20s through their 50s. Table 1 shows the number of people involved in the actual testing under the various driving conditions.

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Table 1 Number of subjects

Driving condition	Japanese		German		American	
	Male	Female	Male	Female	Male	Female
Acceleration	23	7	25	5	18	12
Cruise	16	8	15	5	5	3
Idle	16	8	16	4	17	10

2.2 Sounds Presented in the Evaluations

Sixteen sounds were selected for each of the following driving conditions: under acceleration, cruising and at idle. Binaural measurements were taken on 21 vehicles using an artificial head microphone located in the front passenger seat. In order to determine universal objective evaluation attributes, the focus of attention was to have as many different vehicle models and driving conditions as possible. The composition of models ran from small 3-cylinder through large 8-cylinder powered vehicles. Moderate acceleration, fast acceleration and cruising at speeds between 40 km/h and 150 km/h were used. These presentation sounds were edited to be 2 seconds in length, and in order to limit non-continuous sound generation, an exponential function weighting process was carried out for 0.2 sec at each beginning and end of the signal.

When listening to the sounds, headphones were used, but compensation was made to frequency characteristics and sound level considering headphone characteristics. The sound reproduced was faithful to the original sound.

2.3 Evaluation Attributes

To describe vehicle interior sound attributes, terms such as those shown in Table 2 are often used. Comparing these 12 attributes from the different countries, while there may be differences in feelings, and the impression given by the sound might not be exactly the same, those terms that were roughly equivalent were selected.

In this report, in order to relate the meaning of the words with the sensory feelings, and in order to avoid changing the meaning of the words through translation, we have included the terms in their original languages — Japanese, German, and English.

2.4 Test Method

In carrying out the test while giving weight to judgment accuracy by the subjects, the method of paired comparison⁽²⁾ — where the sounds are listened to and compared with each other — would be the most appropriate. However, with 16 types of presentation sounds, 120 pairs comparing 12 attributes, and furthermore, with 3 types of driving conditions, the test scope was impractical. Therefore, a new test method, a tournament type of paired comparison, was used. With this method, the 16 types of sound were randomly made into 8 pairs, and a comparison judgment made according to evaluation scores, as shown in Table 3. The selected sound was treated as a “winner”, and comparisons continued as a tournament. The subjective difference of each sound in this tournament is calculated by focusing on the losers. In each comparison, the winner’s scores are subtracted from the loser’s score, creating negative scores, and then totaling the scores along each sound’s branches on the elimination tree from the winner. The winner would have 0 points (nothing subtracted). At this time, it is very important for the comparison combinations to be randomly changed, to eliminate the effect of combinations.

A personal computer and a playback system are used for the test, as shown in Fig. 1. The subjects are asked to operate an original application. There is 1 second of silence before each of the two presentation sounds, making a total of 6 seconds. This sequence is repeatedly played until the subject makes a judgment. When the subject makes a judgment, the sound with the higher score wins and so

Table 2 Kinds of attribute for subjective testing

	Japanese	German	American
1	大きさ	laut	Loud
2	こもり感	dröhnend	Booming
3	滑らか感	glatt	Smooth
4	鋭さ感	scharf	Sharp
5	重厚感	klings solide	Solid
6	迫力感	kraftvoll	Powerful
7	軽快感	lebendig	Alive
8	高級感	Exklusivität	Luxury
9	ファントムドライブ	Spaß am fahren	Fun to drive
10	スポーティ感	sportlich	Sporty
11	好み	bevorzugen Sie	Preference
12	のび感	durchzugsstark	Engine extensibility

Table 3 Standard of judgment for subjective testing

Score	Japanese	German	American
0	判断できない	keine von beiden	Undecidable
1	ややそうである	trifft etwas zu	Applicable to some extent
2	そうである	trifft zu	Applicable
3	非常にそうである	trifft voll zu	Applicable to the greatest degree



Fig. 1 System for subjective testing

remains, and the program moves to the next presentation sound. The software program automatically operates this series of events and calculates the difference.

3. Analysis of Sound Perception

3.1 Extracting the main evaluation attributes (comprehensive attributes) perceived inside a car

Based on the order data from each evaluation attribute obtained from the sensory evaluation test, statistical analyses were made. First, with the purpose of quantifying the average perception of ordinary people, an analysis of variance⁽³⁾ was carried out for each of the 12 types of evaluation attributes. Attributes that differed between subjects were eliminated. Table 4 gives the analysis results for the three subject markets. At this time, attributes with a significant probability of 0.05 or more were eliminated from analysis.

Next, principal component analysis⁽⁴⁾ was carried out, to extract the main perceived evaluation attributes for sounds inside a car.

The results of this principal component analysis showed that for Japanese people, during acceleration the factor load weightings for “sporty”, “engine extensibility” and “powerful” were 0.981, 0.952, and 0.877 respectively, as shown in Table 5, so the first major component is defined as the sporty series attributes.

In the same way, when an analysis was made of each country’s driving conditions, although the number one and number two components differed according to driving conditions, they were the sporty series or the luxury series, or even a combination of the two, and it was obtained that the sporty series and the luxury series can mainly be expressed in 2 axes. Therefore, the sporty series and the luxury series resulted in comprehensive evaluation attributes — for Japanese “supo-ti kan” and “koukyuu kan”, for Germans “sportlich” and “Exklusivität”, and for Americans “Sporty” and “Luxury”.

The words of the comprehensive evaluation attributes, “sporty” and “luxury”, are not words that originally describe sounds. However, the reason they were taken up at this time is assumed to be a result of ordinary people passively learning automotive sounds in the market, and these attributes are ordinarily identified as the product characteristics of automobiles. In addition, these attributes indicate concepts for automobile development.

3.2 Selection of Evaluation Attributes that are Vital Elements (Elemental Attributes) in Comprehensive attributes

As previously noted, the words for comprehensive attributes do not, in themselves, describe sound, resulting in a tendency toward vagueness. If it is made clear what sort of

Table 4 Result of analysis of variance

(1) Japanese

Attribute	Acceleration	Cruise	Idle
大きさ	0.000	0.000	0.000
こもり感	0.000	0.000	0.000
滑らか感	0.000	0.000	0.000
鋭さ感	0.000	0.000	0.000
重厚感	0.000	0.001	0.000
迫力感	0.000	0.000	0.000
軽快感	0.000	0.612	0.000
高級感	0.002	0.000	0.000
ファントムドライブ	0.000	0.000	0.000
スポーティ感	0.000	0.000	0.004
好み	0.000	0.000	0.000
のび感	0.000		

(2) German

Attribute	Acceleration	Cruise	Idle
laut	0.000	0.000	0.000
dröhnend	0.000	0.000	0.000
glatt	0.000	0.000	0.000
scharf	0.000	0.000	0.000
klingt solide	0.000	0.000	0.000
kraftvoll	0.000	0.000	0.000
lebendig	0.000	0.000	0.000
Exklusivität	0.000	0.000	0.000
Spaß an fahren	0.000	0.660	0.149
sportlich	0.000	0.000	0.006
bevorzugen Sie	0.000	0.000	0.000
durchzugsstark	0.000		

(3) American

Attribute	Acceleration	Cruise	Idle
Loud	0.000	0.000	0.000
Booming	0.000	0.005	0.000
Smooth	0.000	0.000	0.000
Sharp	0.000	0.105	0.049
Solid	0.261	0.830	0.006
Powerful	0.000	0.033	0.185
Alive	0.000	0.003	0.000
Luxury	0.000	0.000	0.000
Fun to drive	0.000	0.350	0.069
Sporty	0.000	0.341	0.360
Preference	0.000	0.000	0.000
Engine extensibility	0.000		

elemental attributes comprise the comprehensive attributes, then the information will be more detailed and will be easier to link to physical properties. Therefore, multiple regression analyses⁽⁴⁾ were carried out in order to extract the elemental attributes comprising the comprehensive attributes.

Table 5 Result of principle component analysis

(1) Japanese

Driving condition	Acceleration			Cruise		Idle		
Attribute	Factor loading 1	Factor loading 2	Factor loading 3	Factor loading 1	Factor loading 2	Factor loading 1	Factor loading 2	Factor loading 3
大きさ	0.740	-0.522	-0.228	0.942	-0.250	0.928	-0.149	0.256
こもり感	-0.611	0.484	0.529	-0.591	0.782	-0.072	0.936	0.037
滑らか感	0.055	0.944	0.037	-0.778	0.498	-0.891	-0.006	-0.307
鋭さ感	0.881	-0.256	-0.297	0.947	-0.253	0.531	-0.597	-0.212
重厚感	-0.063	0.081	0.979	-0.100	0.976	0.465	0.753	0.357
迫力感	0.877	-0.398	0.151	0.958	-0.143	0.909	0.253	0.269
軽快感	0.779	0.330	-0.460			-0.786	-0.490	-0.033
高級感	-0.325	0.865	0.079	-0.767	0.605	-0.905	0.196	0.133
スポーティ感	0.981	-0.088	-0.138	0.856	-0.306	0.174	0.194	0.952
のび感	0.952	-0.032	-0.006					
Eigenvalue	5.057	2.494	1.640	4.987	2.419	4.455	2.202	1.332
Variance %	50.566	24.941	16.395	62.338	30.240	49.497	24.466	14.800
Cumulative %	50.566	75.506	91.902	62.338	92.577	49.497	73.962	88.763

(2) German

Driving condition	Acceleration		Cruise		Idle	
Attribute	Factor loading 1	Factor loading 2	Factor loading 1	Factor loading 2	Factor loading 1	Factor loading 2
laut	0.688	0.651	0.828	0.467	0.675	0.709
dröhnend	0.428	0.611	0.773	0.531	0.458	0.81
glatt	-0.476	-0.803	-0.553	-0.814	-0.832	-0.484
scharf	0.578	0.651	0.812	0.464	0.85	0.26
klingt solide	-0.476	-0.802	-0.506	-0.857	-0.947	-0.042
kraftvoll	0.853	0.424	0.791	0.526	-0.215	0.946
lebendig	0.883	0.426	0.809	0.54	0.667	0.605
Exklusivität	-0.172	-0.974	-0.501	-0.85	-0.965	-0.122
sportlich	0.889	0.389	0.805	0.49	0.521	0.74
durchzugsstark	0.941	0.26				
Eigenvalue	4.657	4.037	4.684	3.645	4.671	3.285
Variance %	46.565	40.374	52.04	40.5	51.902	36.495
Cumulative %	46.565	86.939	52.04	92.54	51.902	88.397

(3) American

Driving condition	Acceleration		Cruise		Idle	
Attribute	Factor loading 1	Factor loading 2	Factor loading 1	Factor loading 2	Factor loading 1	Factor loading 2
Loud	0.673	0.665	0.885	0.142	-0.724	0.648
Booming	0.622	0.664	0.136	0.976	-0.688	0.58
Smooth	-0.314	-0.875	-0.903	-0.3	0.892	-0.284
Sharp	0.83	0.457			-0.053	0.92
Solid					0.882	0.122
Powerful	0.901	0.334	0.789	0.462		
Alive	0.842	0.472	0.928	-0.047	-0.823	0.348
Luxury	-0.204	-0.93	-0.862	-0.252	0.829	-0.528
Sporty	0.904	0.371				
Engine extensibility	0.919	0.136				
Eigenvalue	4.851	3.211	3.843	1.342	3.936	2.098
Variance %	53.901	35.681	64.045	22.363	56.236	29.972
Cumulative %	53.901	89.582	64.045	86.408	56.236	86.207

As shown in Table 6, Japanese people in particular felt a sound was “supo-ti kan”(sporty) the more it was “hakuryoku kan”(powerful) and “keikai kan”(alive), and felt it as “koukyuu kan”(luxury) the less it was “ookisa kan”(loud) and the more it was “nameraka kan”(smooth). The Germans felt a sound was “sportlich”(sporty) the more it was “lebendig”(alive), and that it was “Exklusivität”(luxury) the more it was “klingt solide”(solid) and “glatt”(smooth). In addition, Americans found a sound “sporty” the more it was powerful and alive, while as “luxury” the less it was loud and the more it was smooth.

The sensory evaluation tests carried out in this report were divided according to driving conditions, in order to improve the evaluation accuracy of the subjects. The partial regression coefficients in the multiple regression equation, obtained through analysis, are different. It was thought that the cause of the difference in partial regression coefficients was due to changes in sound perception due to differences in driving conditions, or that the partial regression coefficient, which is a probability factor, differs due to the presentation sound being different without change in perception. Structural equation modeling was used to make this clear.⁽⁵⁾

Structural equation modeling is a statistical method that can analyze, in a single group, models having multiple cause and effect relationships. It is also called 2nd generation multivariate analysis. Thinking about different driving conditions, Table 7 gives the results of analysis into conditions in which the cause and effect factors of elemental attributes corresponding to comprehensive attributes are the same, and conditions in which the cause and effect factors are different. That is to say, conditions when perceptions were the same under different driving conditions, and conditions when the perceptions were different. Whether it was Japanese people, Germans, or Americans, following Akaike Information Criteria AIC⁽⁵⁾ (a model where the smaller the value the better), the model with the same perceptions had smaller values. Therefore, it was considered that sound perceptions do not change, even if driving conditions are different. Equations were found that express the links with the elemental attributes, as shown in Table 8.

In addition, using an analysis of variance by country eliminated sporty feeling during idling. The multiple regression correlation factor was low, and structural equation modeling a common cause and effect coefficient could not be

found. Therefore, it was not possible to comprehensively quantify driving conditions. It was difficult for the presentation sounds during idling to give the impression of being sporty, and it was thought to be due to large variation between the subjects.

4. Relating Subjective Evaluation Attributes with Psychoacoustic Metrics

4.1 A Revision to Conventional Psychological Evaluation Attributes

Through conventional research, the authors previously reported the attribute expressing the amount of auditory stimulus⁽⁶⁾ as “loudness”, and expressing the level of fluctuation as “level of sound fluctuation unpleasantness”, etc. However, in further study, “level of sound fluctuation unpleasantness” was revised, becoming “strength of fluctuation”. The “unpleasantness” associated with the words “level of unpleasantness” is something subjective that varies by individual and depends on values. It was judged inappropriate as an expression of the amount of stimulation.

Table 7 Result of sound perception as same or different depends on different driving conditions

Country	Comprehensive attribute	Sound perception	AIC	Result
Japanese	高級感	Same	-15.97	Better
		Different	-12	-
	スポーティ感	Same	- 6.745	Better
		Different	- 6	-
German	Exklusivität	Same	-16.126	Better
		Different	-12	-
	sportlich	Same	- 1.998	Better
		Different	0	-
American	Luxury	Same	-16.076	Better
		Different	-12	-

Table 6 Result of multiple regression analysis

Country	Comprehensive attribute	Driving condition	Multiple regression formula		
Japanese	高級感	Acceleration	= -0.40 × 大きさ感	+0.55 × 滑らか感	
		Cruise	= -0.22 × 大きさ感	+0.78 × 滑らか感	
		Idle	= -0.65 × 大きさ感	+0.21 × 滑らか感	
	スポーティ感	Acceleration	= 0.62 × 迫力感	+0.53 × 軽快感	
		Cruise	= 0.80 × 迫力感		
		Idle	= 1.31 × 迫力感	+0.80 × 軽快感	-0.55 × 鋭さ感
German	Exklusivität	Acceleration	= 0.41 × klingt solide	+0.51 × glatt	
		Cruise	= 0.98 × klingt solide		
		Idle	= 0.77 × klingt solide	+0.22 × glatt	
	sportlich	Acceleration	= 0.77 × lebendig	+0.23 × scharf	
		Cruise	= 0.95 × lebendig		
		Idle	= 0.41 × lebendig	+0.51 × klingt solide	-0.92 × glatt
American	Luxury	Acceleration	= -0.33 × Loud	+0.55 × Smooth	
		Cruise	= -0.14 × Loud	+0.82 × Smooth	
		Idle	= -0.51 × Loud	+0.49 × Smooth	
	Sporty	Acceleration	= 0.30 × Powerful	+0.66 × Alive	

Table 8 Result of structural equation modeling (Equation)

Country	Comprehensive attribute	Driving condition	Multiple regression formula
Japanese	高級感	Acceleration	= $-0.32 \times \text{大きさ}$ $+0.65 \times \text{滑らか感}$
		Cruise	
		Idle	
	スポーティ感	Acceleration	= $0.64 \times \text{迫力感}$ $+0.52 \times \text{軽快感}$
		Cruise	
		Idle	
German	Exklusivität	Acceleration	= $0.77 \times \text{klingt solide}$ $+0.21 \times \text{glatt}$
		Cruise	
		Idle	
	sportlich	Acceleration	= $0.82 \times \text{lebendig}$ $+0.17 \times \text{scharf}$
		Cruise	
		Idle	
American	Luxury	Acceleration	= $-0.34 \times \text{Loud}$ $+0.63 \times \text{Smooth}$
		Cruise	
		Idle	
	Sporty	Acceleration	= $0.30 \times \text{Powerful}$ $+0.66 \times \text{Alive}$

4.2 The Introduction of New Psychoacoustic Metrics

At this time, in addition to conventional attributes, a “loudness of pure tone” calculation algorithm was conceived because it is thought to be important as an element that is part of a sporty sound. “Loudness of pure tone” is an attribute that becomes larger as a single pure component becomes dominant, among the complex sounds in a critical band (band, hereafter). Conceptually, there is a reciprocal relationship between “strength of fluctuation” and “loudness of pure tone”.

In addition, “percent of loudness” was introduced to express the proportion of “loudness” in each band, against the total band addition value. “Percent of fluctuation intensity” was another attribute introduced, expressing the amount of protrusion of “fluctuation intensity” in a band that is caught between two bands.

4.3 Relating Elemental Attributes with Psychoacoustic Metrics

In order to relate the elemental attributes comprising the comprehensive attributes with the psychoacoustic metrics that indicate auditory stimulus calculated from physical properties, the same methods described in Section 3 were utilized. The psychoacoustic metrics necessary to develop relationships were extracted using multiple regression analysis. Through structural equation modeling, the applicability of driving conditions was verified; and the cause and effect factor was calculated. As a result, shown in Fig. 2, it was possible to quantify the attributes by country — psychoacoustic metrics calculated from physical properties, elemental attributes, and comprehensive attributes, in that order, including their relationships. For example, in explaining the Japanese “luxury” in Fig. 2-(1), the smaller the total band “loudness” and the smaller the “fluctuation intensity”, the more it felt like “luxury”. In particular, “fluctuation intensity” was a factor in the loss of luxury

feeling the higher the frequency component. For the Japanese “sporty” in Fig. 2-(2), there is a strong relationship between the 2–9 Bark “loudness of pure tone”, the 2 Bark “percent of loudness”, and the total band “loudness”. The larger these values, the higher the “sport feeling”. Looking at it this way, in general, although there are differences in the level of effect in each band, in all countries there were the commonalities that the smaller the “loudness” and “fluctuation intensity”, the more it is “luxury” and the larger the “loudness” and “loudness of pure tone” the more sporty it felt.

The Japanese “sporty” changes especially when 1 Bark “loudness” increases or decreases as shown in Fig. 2-(2). For example, when 1 Bark “loudness” becomes large, “hakuryoku kan”(powerful) increases and “keikai kan”(alive) drops, and even if the main element of sporty changes from “keikai kan”(alive) to “hakuryoku kan”(powerful), there is the feeling that the “supo-ti kan”(sporty) has not changed. This is because the symbol for the cause and effect factor for the 1 Bark “percent of loudness” that is an element of “hakuryoku kan”(powerful), and the symbol for the cause and effect factor for the 1 Bark “loudness” that is an element of “keikai kan”(alive) were reversed.

5. Analysis of Preferences

The previous sections have been concerned with comprehensive attributes for sounds inside a car. This section analyzes the preferences of the subjects.

Assuming that there are patterns in subject preferences, a cluster analysis was carried out for classification. Also, by evaluating sounds that are rich in sound varieties, the differences in each subject’s preferences are evident, and the categories are made clear. Therefore, the subject of the analysis was sound during acceleration, which showed a low correlation (Table 9) between “sporty” and “luxury” in the comprehensive attributes.

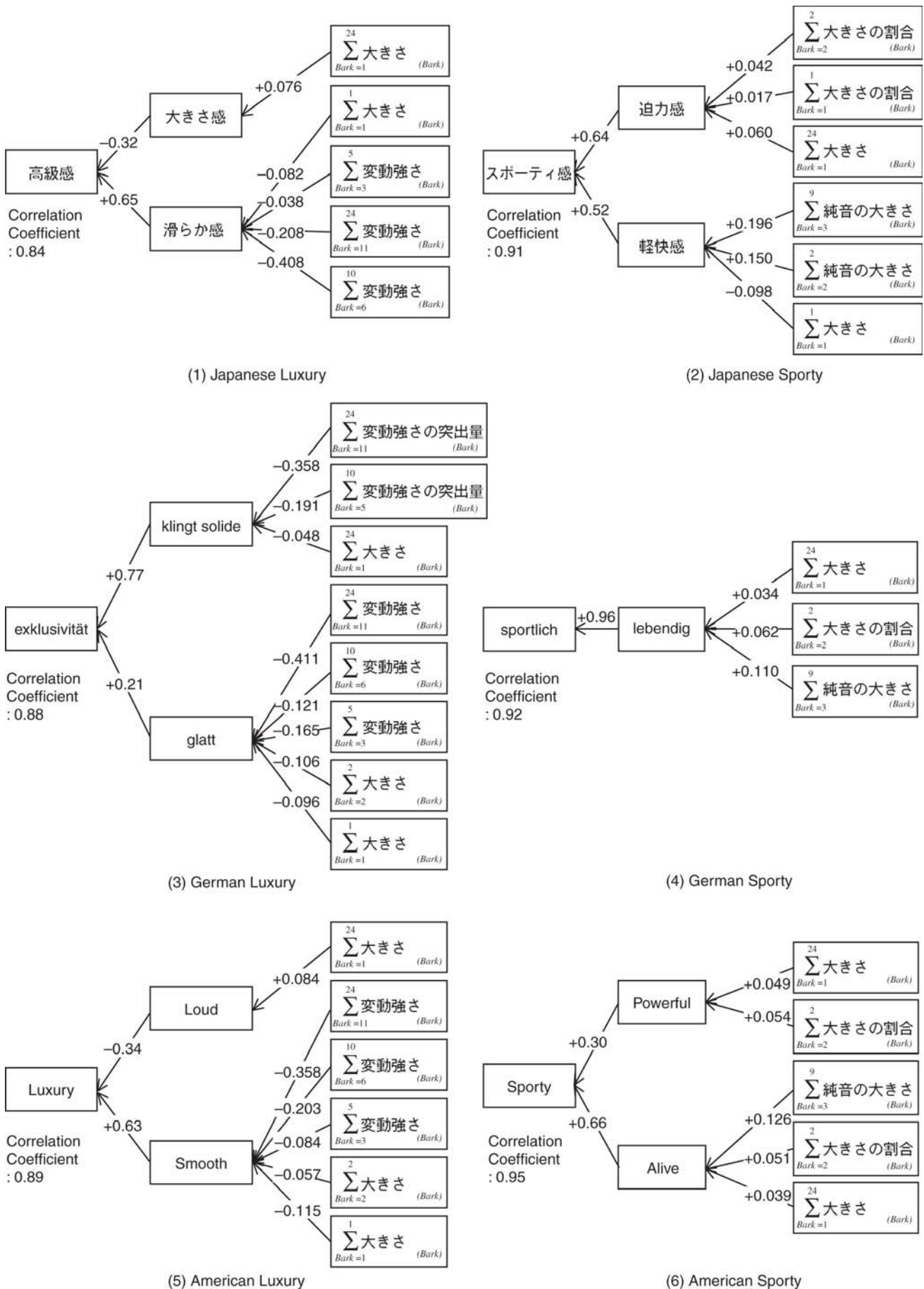


Fig. 2 Sound quality feeling model

Table 9 Correlation of luxury and sporty

Country	Acceleration	Cruise
Japanese	-0.41	-0.81
German	-0.53	-0.82
American	-0.54	

As shown in Table 10, the Japanese subjects were divided into two clusters — the subject group that preferred a sporty sound, having a correlation of 0.89 between sporty and prefer; and the subject group that preferred luxury, having a correlation of 0.95 between luxury and prefer. The subject group that preferred a sporty feel was 59% of all subjects, while those in the group that preferred luxury were 41% (Fig. 3). In addition, examining whether or not people with different preferences had the same perceptions of the

Table 10 Correlation of preference and each attribute (Japanese)

	高級感	スポーティ感	大きさ	こもり感	滑らか感	鋭さ感	重厚感	迫力感	軽快感
All subjects	0.36	0.50	0.15	-0.04	0.65	0.31	-0.22	0.24	0.68
Cluster 1	0.95	-0.66	-0.76	0.74	0.90	-0.72	0.21	-0.72	0.24
Cluster 2	0.11	0.89	0.68	-0.65	0.57	0.80	0.02	0.79	0.79

Table 11 Correlation of comprehensive attributes depends on preference (Japanese)

	Luxury favorite subjects “好み”	Sporty favorite subjects “好み”
All subjects “好み”	0.15	0.73
	Luxury favorite subjects “高級感”	Sporty favorite subjects “高級感”
All subjects “高級感”	0.93	0.86
	Luxury favorite subjects “スポーティ感”	Sporty favorite subjects “スポーティ感”
All subjects “スポーティ感”	0.92	0.98

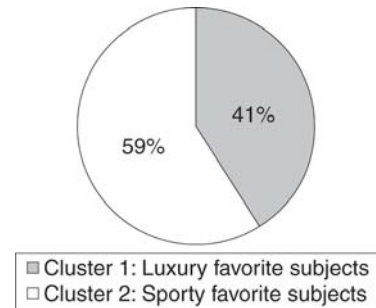


Fig. 3 Cluster of preference (Japanese)

Table 12 Correlation of preference and each attribute (American)

	Luxury	Sporty	Loud	Boom	Smooth	Sharp	Solid	Powerful	Alive
All subjects	0.51	0.27	-0.10	-0.11	0.42	0.21	0.36	0.25	0.22
Cluster 1	0.77	-0.49	-0.66	-0.63	0.79	-0.53	0.11	-0.44	-0.48
Cluster 2	-0.17	0.86	0.61	0.57	-0.52	0.78	0.60	0.80	0.85

Table 13 Correlation of comprehensive attributes depends on preference (American)

	Luxury favorite subjects “Preference”	Sporty favorite subjects “Preference”
All subjects “Preference”	0.63	0.55
	Luxury favorite subjects “Luxury”	Sporty favorite subjects “Luxury”
All subjects “Luxury”	0.93	0.93
	Luxury favorite subjects “Sporty”	Sporty favorite subjects “Sporty”
All subjects “Sporty”	0.96	0.96

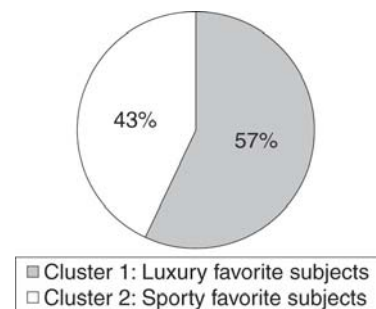


Fig. 4 Cluster of preference (American)

comprehensive attributes or not, it was considered that there is no difference in comprehensive attributes, from the results of correlation functions for each cluster, as shown in Table 11. For the Americans, too, the same analysis was carried out, and the results (Tables 12, 13 and Fig. 4) showed that 43% liked the sporty feeling, and 57% preferred a luxury feel. In the same way as with the Japanese, concerning comprehensive attributes, there is the same in perception due to preferences. On the other hand, almost all the German subjects — 86% (Table 14, Fig. 5) — preferred luxury, and there were almost none that preferred the sporty sound like the Japanese and Americans.

From these results, it is important to consider preferences according to the market when controlling sound quality.

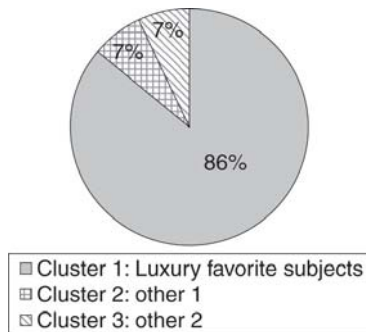


Fig. 5 Cluster of preference (German)

6. Sound Quality Evaluation System

Until now, we have used an original application that can calculate psychoacoustic metrics corresponding to a signal that was binaurally recorded using an artificial head microphone. An algorithm that calculates comprehensive attributes was added to this, and as shown in Fig. 6, software was developed. Furthermore, it has become a rational system that is integrated from analysis through trial sounds, by adding functions such as a general analysis function that can carry out conventional frequency analysis, etc., and a function that can carry out sound filtering and compare trial sounds before and after filtering in real time, among others.

7. Examples of Application

Fig. 7 shows an application of this method for interior sound to a Japanese vehicle of about 2,000 cc of engine displacement. This example is Japanese perceptions of luxury and sporty feeling when the vehicle was driven in 2nd gear in a fully loaded state. As revs rise, “loudness” and “fluctuation intensity”, main psychoacoustic metrics for luxury sound, grow larger, and luxury sound drops. Also, as revs rise, “loudness of pure tone”, a main psychoacoustic metric for sporty, grows larger, and the sporty sound increases.

8. Summary

Through sensory evaluation tests by ordinary Japanese, Germans, and Americans, the following facts were obtained.

Table 14 Correlation of preference and each attribute (German)

	Exklusivität	sportlich	laut	dröhnend	glatt	scharf	klingsolide	kraftvoll	lebendig
All subjects	0.92	-0.45	-0.72	-0.65	0.75	-0.66	0.73	-0.53	-0.49
Cluster 1	0.95	-0.55	-0.76	-0.71	0.80	-0.69	0.76	-0.59	-0.56
Cluster 2	0.06	0.24	-0.25	0.13	-0.18	0.13	0.29	0.49	-0.01
Cluster 3	0.53	-0.08	-0.46	-0.06	-0.15	-0.58	0.15	0.32	0.44

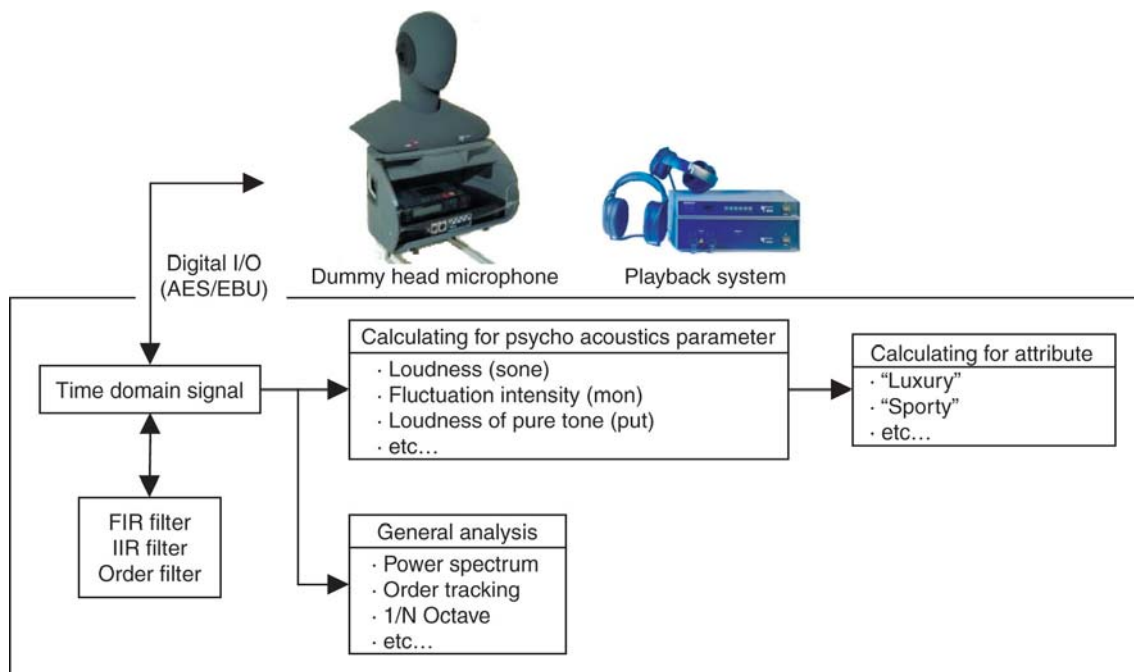


Fig. 6 Sound quality evaluation system

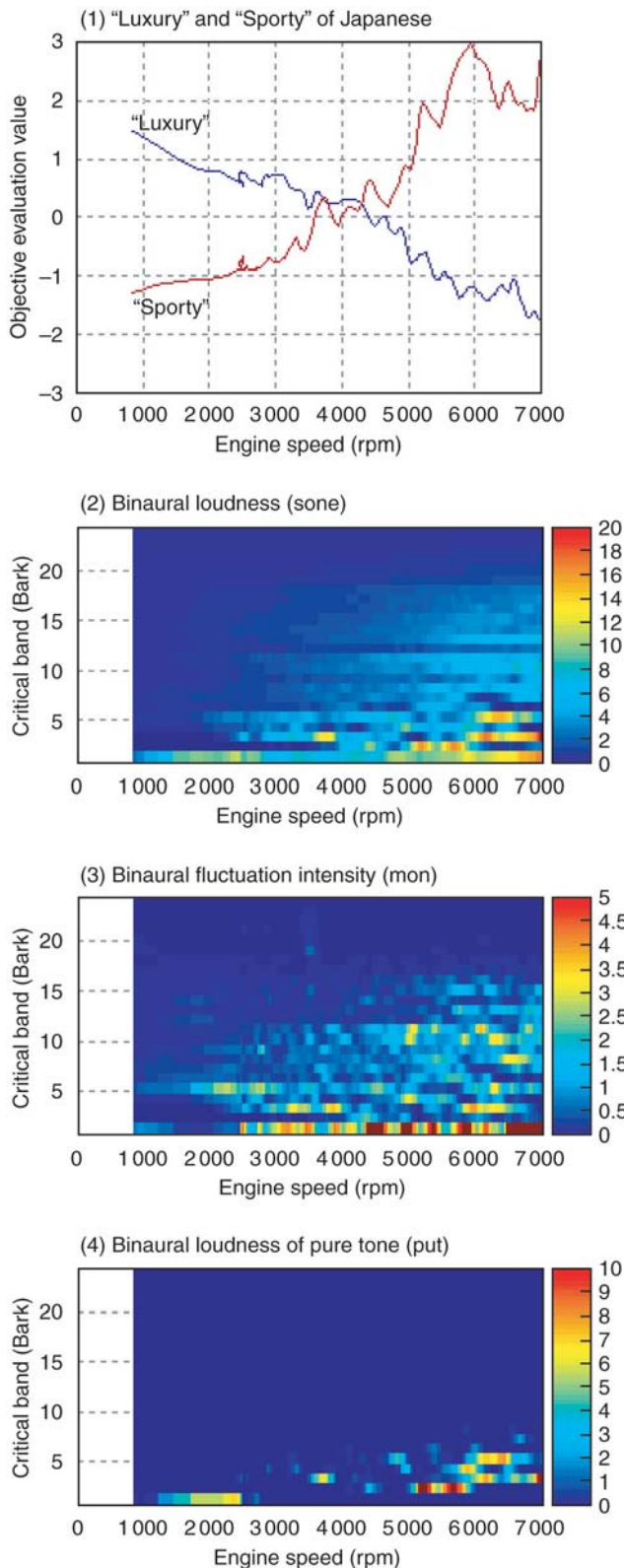


Fig. 7 Objective evaluation value of sound in cabin

- (1) Regarding sounds perceived in a car cabin, although there are differences of degrees in people of different countries, it was learned that, in the main, perceptions can be expressed on the 2 axes of whether or not it gives a luxury feel, and whether or not it is sporty. It was also possible to quantify these perceptions, using objective numbers.
- (2) Even if driving conditions were different, there was no difference in perceptions of luxury components and

sporty components. However, at this time it is not possible to quantify sporty feeling when idling.

- (3) Making a comparison between countries concerning the luxury component and the sporty component, each attribute comprising the psychoacoustic metrics were roughly the same, but the Japanese sporty component ("supo-ti kan") had a special feature. When there was a 1 Bark loudness increase or decrease, there was a tendency towards reciprocation between "hakuryoku kan" (powerful) and "keikai kan" (alive). These cancel each other out, and are not really seen as a change to "supo-ti kan"(sporty).
- (4) As for preference regarding sound during acceleration, approximately 60% of the Japanese subject group preferred the "supo-ti kan" (sporty) feel, while 40% preferred the "koukyuu kan" (luxury). Approximately 40% of the American subject group preferred "sporty" while 60% preferred "luxury". Almost 90% of the German subject group preferred "Exklusivität" (luxury). Therefore, it is not possible to determine an unambiguously good sound, and it is necessary to make sound quality improvements giving consideration to each market's preferences.
- (5) Modifying the conventional sound quality evaluation system, psychoacoustic metrics were added, a system was developed that can also calculate comprehensive attributes.

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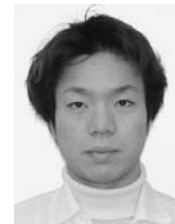
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