inter.noise 2004
Prague • Czech Republic • August 22–25

The 33rd International Congress and Exposition
on Noise Control Engineering

Categorisation of engine sound

Norio Kubo[a,b], Volker Mellert[b], Reinhard Weber[b], Jens Meschke[a]

[a]Volkswagen AG, Konzernforschung, K-EFFD/A, Brieffach 1499, D-38436 Wolfsburg, Germany
[b]Carl von Ossietzky Universität, Institut für Physik /Akustik, D-26111 Oldenburg, Germany

[a] norio.kubo@volkswagen.de

Abstract [452] Quietness of car interior noise is not the only objective for the creation of engine sound. Nowadays the market requires 'right sound for right car'. Thus, customers' favourite sound should be analysed. This report presents results of research work considering engine sounds and customers' preferences. Meaning of engine sounds has been widely investigated by semantic differential methods. However, it has not been clearly examined how car impressions like 'sporty/luxury' relate to psychoacoustic impressions like 'pleasant/powerful/metallic'. With the help of semantic differentials subjective evaluation of measured car sounds were conducted. Sounds in different driving conditions were also examined. It was found that perceptions of sounds in acceleration and constant speed were clearly unequal. Customers' expectations of sounds according to driving conditions were investigated. Some researches indicate that there are two favourite groups of car sounds (sporty sound and luxury sound). Study in this paper investigated to see reactions of sporty and luxury car owners to sporty sound or luxury sound. The result shows that different car owner groups have different perception. Sporty car owner are more sensitive to sporty car sounds. Such bias among car owner groups should be considered in the future research.

1 INTRODUCTION

Categorisation of engine sound was done in these steps, 1) finding the perceptual space and meaning of sounds, 2) identifying spatial representation "sporty" and "luxurious", 3) classifying various sounds, 4) understanding bias from different car owners.
It is well-known that car/machinery sound is psycho-acoustically categorised by three factors, often described by "powerful", "pleasant" and "metallic" [1]. Some researches reported for car sounds only with "powerful" and "pleasant" [3], [4].
On the other hand, car manufactures investigate to improve car interior sound as impressions, "sporty" and "luxurious". However, it is not clear to describe the relationship between psycho-acoustical factors and car manufactures' impressions [2]. Therefore, this research looks into this relationship as well.
Additionally, some reports indicate that test persons evaluate same sounds differently due to their personal preferences [5]. Since this research aims to understand engine sound, different car owners participated in the listening tests. Test persons vary from high sporty car owners (e.g. Porsche Boxster), high luxurious car owners (e.g. Mercedes-Benz S-Class), to normal car users (e.g. Volkswagen Golf).

2 PERCEPTUAL SPACE AND MEANING OF ENGINE SOUNDS

2.1 Known evaluations and impression “sporty” and “luxurious”

Psycho-acoustically sound of car engine is known to be evaluated by three factors, “powerful”, “pleasant” and “metallic”. However, several car manufactures tend to improve car sounds as “sporty” or “luxurious”. Thus, test was conducted to understand the relationship between psychoacoustics and the categories “sporty” and “luxurious”.

2.2 Semantic differential method – Test method

Semantic differential method was used as useful and well known tool of analysing perceptual space. Since people hear interior car sound differently in different car running conditions [5], so that two tests conditions (constant speed and acceleration) were conducted.

SUBJECTS 17 normal hearing subjects took part in the experiment. Test persons have a mean age 28.6 years (range: 24-40 years) and consist of 13 male and 4 female. The majority of participators were German, 15 people, and 2 non-German who live in Germany at least 4 years and have a good understanding of German language.

STIMULI All test signals were based on stereophonic measurement of interior car sound at driver’s ears. Driving conditions consist of constant speed and WOT (Wide Open Throttle) acceleration. Both tests present 10 signals. Sounds of 6 cars were recorded in 2nd and 3rd gear for acceleration. Sounds of same 6 cars were measured in constant speed at 50 and 100 km/h. Table 1 and 2 show its variation.

Gear	**2nd**	**3rd**
VW Golf R32	Signal 1	Signal 2
VW Polo	Signal 3	-
VW Golf TDI	Signal 4	Signal 5
Jaguar X type	Signal 6	Signal 7
Mercedes-Benz S600	Signal 8	-
Toyota Lexus SC430	Signal 9	Signal 10

Table 1: *Test signals in WOT acceleration*

Speed	**50 km/h**	**100 km/h**
VW Golf R32	-	Signal 1
VW Polo	Signal 2	-
VW Golf TDI	Signal 3	Signal 4
Jaguar X type	Signal 5	Signal 6
Mercedes-Benz S600	Signal 7	Signal 8
Toyota Lexus SC430	Signal 9	Signal 10

Table 2: *Test signals in constant speed*

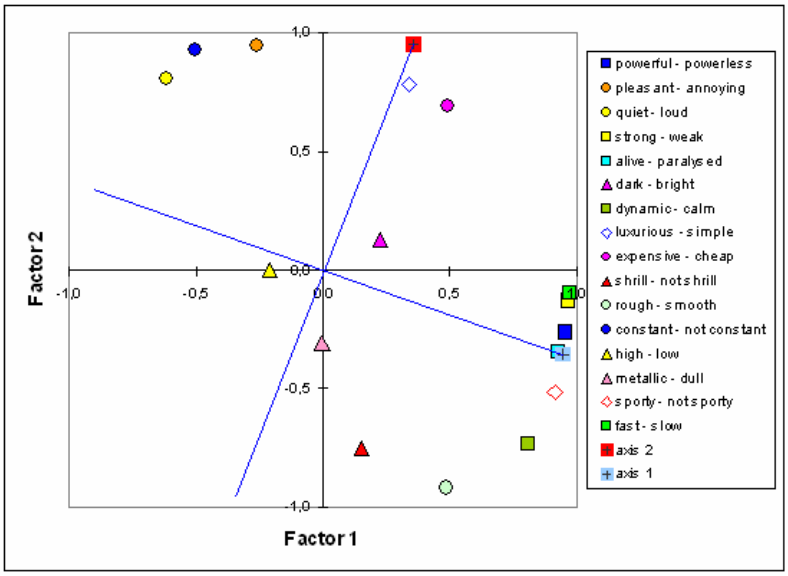
EXPERIMENT SET-UP A computer program controls the presentation of the test signals. The stimuli were played back via a 16-bit sound card and an amplifier. They were delivered to headphones and subwoofers in a quiet room. Each signal was presented for around 10 seconds in random order. A semantic differential of 15-16 bipolar adjective pairs in German were used. (Table 3) Subjects marked their impression on a scale 1-7 for each sound. Each sound was twice presented in a separate evaluation. The answers (scales) of the two presentations were averaged. In the case that answers for same sounds were 3 scales different or more, these answers were eliminated.

In German (Original)	In English
kraftlos – kräftig	powerless - powerful
angenehm – lästig	pleasant – annoying
leise – laut	quiet – loud
stark – schwach	strong – weak
lahm – lebendig	paralysed – alive
ruhig – dynamisch	calm – dynamic
dunkel – hell	dark – bright
schlicht – luxuriös	simple – luxurious
billig – teuer	cheap – expensive
nicht schrill – schrill	not shrill – shrill
glatt – rauh	smooth – rough
ungleichmäßig – gleichmäßig	not constant – constant
tief – hoch	low – high
unsportlich – sportlich	not sporty – sporty
metallisch – dumpf	metallic – dull
schnell – langsam (only for acceleration)	fast – slow

Table 3: *Contents of adjective pairs*

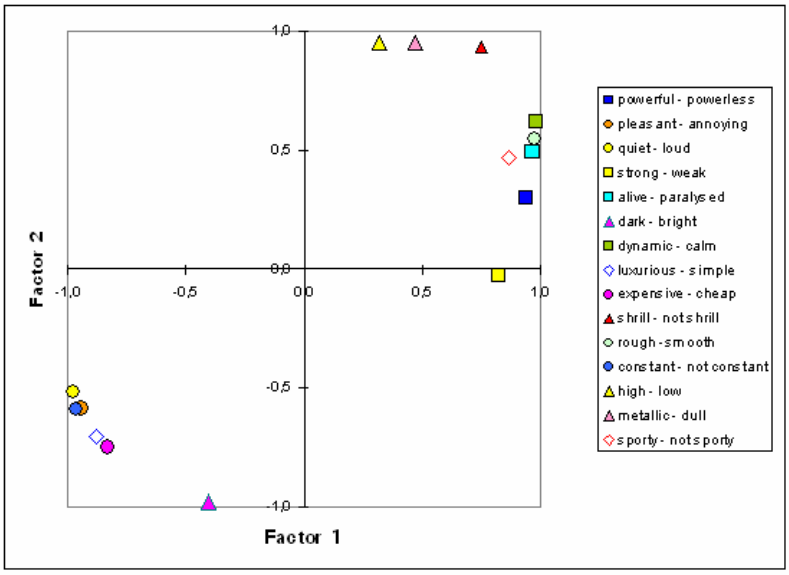
2.3 Result – Factor analysis

The following figures give the result of the factor analysis for adjective pairs.



	Factor 1 "powerful"	Factor 2 "pleasant"	Factor 3 "metallic"
fast - slow	0,971	-0,099	-0,146
strong - weak	0,968	-0,132	-0,267
powerful - powerless	0,956	-0,264	-0,207
alive - paralysed	0,927	-0,347	0,114
sporty - not sporty	0,914	-0,512	-0,110
dynamic - calm	0,808	-0,735	0,038
pleasant - annoying	-0,261	0,942	-0,103
constant - not constant	-0,505	0,926	-0,213
rough - smooth	0,489	-0,919	-0,038
quiet - loud	-0,612	0,804	0,210
luxurious - simple	0,340	0,781	-0,400
shrill - not shrill	0,156	-0,750	0,729
expensive - cheap	0,496	0,690	-0,461
dark - bright	0,229	0,127	-0,968
high - low	-0,206	-0,002	0,962
metallic - dull	-0,003	-0,312	0,961
Varience (%)	46,9	30,5	16,8
Cumulative (%)		77,4	94,2

Figure 1: *Factor analysis in acceleration condition*



	Factor 1 "pleasant"	Factor 2 "metallic"
dynamic - calm	0,983	0,618
rough -smooth	0,977	0,546
quiet - loud	-0,976	-0,515
alive - paralysed	0,968	0,488
constant - not constant	-0,964	-0,593
pleasant - annoying	-0,941	-0,587
powerful - powerless	0,943	0,301
luxurious - simple	-0,877	-0,706
sporty - not sporty	0,865	0,467
expensive - cheap	-0,831	-0,751
strong - weak	0,824	-0,024
dark - bright	-0,404	-0,981
high - low	0,321	0,947
metallic - dull	0,470	0,953
shrill - not shrill	0,754	0,936
Varience (%)	76,9	16,1
Cumulative (%)		93,0

Figure 2: *Factor analysis in constant speed*

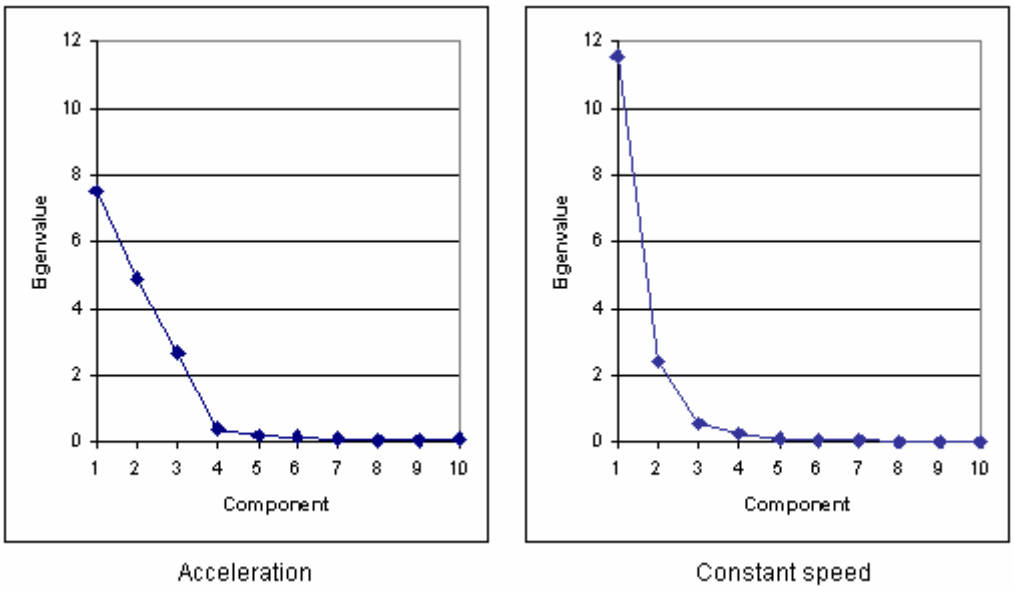


Figure 3: *Eigenvalues of these factor analyses*

NOTE - Both factor analyses were calculated with Promax rotation and Kaiser normalization.
- The axes in figure 1 were used for classification of engine sound (See chapter 3)

2.4 Discussion – Meaning of “sporty” and “luxurious”

The two different test conditions (steady-state and acceleration) show a perceptual space of two and three dimensions, respectively, indicating that the test persons assess the sound differently for accelerated and constant speed.
In the test case of acceleration the dimension “powerful” is interpreted as “sporty” and the dimension “pleasant” includes “luxurious”. Additionally “dynamic” and “alive” are closely related to “sporty”, on the other hand, “luxurious” has no adjectives in local origins on the perceptual space.

However, in constant speed the “powerful” and “pleasant” dimensions have merged, or cannot be discriminated. The adjectives “sporty” and “luxurious” are now in a one-dimensional opposite meaning, as well as the relationship between “pleasant” and “powerful”. In the acceleration condition it turns out that “luxurious” is not correlated with “sporty” at all and it is linear independent from this assessment and thus located perpendicular to “sporty” in the space of perception. (Figure 4)
Changing to the subject, “metallic” is always independent from “powerful” and “pleasant” by both running conditions.
Therefore, psycho-acoustical factors can describe “sporty” and “luxurious”.

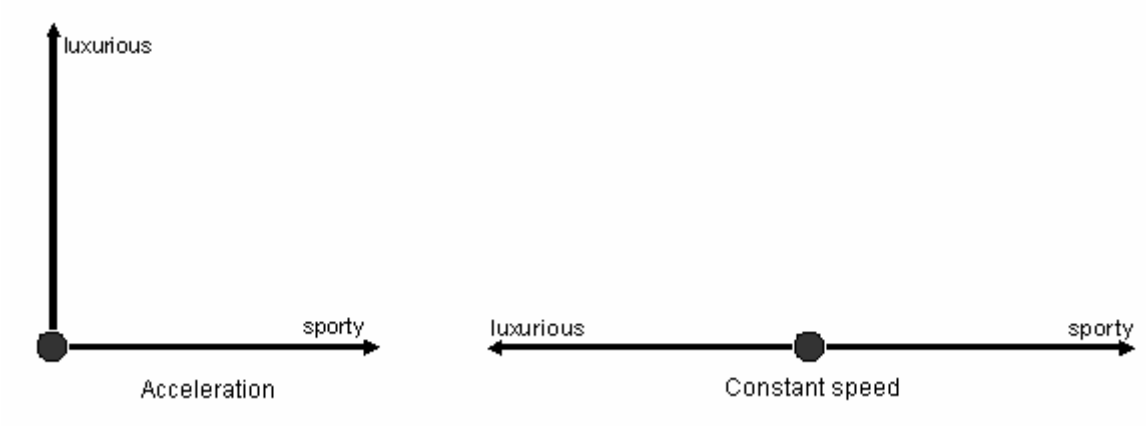


Figure 4: *Meanings in different test condition*

3 CLASSIFICATION OF ENGINE SOUND

3.1 Creation of “car sound map”

As it was discussed in chapter 2, sounds in acceleration condition have perpendicular relationship between “sporty” and “luxurious” in perceptual space. It would mean that sounds of accelerated motion are more suitable for classifying engine sound than these of constant speed. Therefore, a classification chart named “car sound map” was considered in acceleration.
DEFINITION OF AXES Since ”sporty” has close adjective pairs, a symbolic axis is drawn represented by averaged value over factor loads of six adjective pairs, “fast-slow”, “sporty-not sporty”, “alive-paralyzed”, “powerful-powerless”, “dynamic-calm” and “strong-weak”, described as “axis 1” in figure 1. A perpendicular axis to newly averaged “sporty-not sporty” over six adjective pairs is also shown, described as “axis 2” in figure 1.
SOUND VALUES OF CARS A load value of each car was calculated while factor analysis was measured. Each load value was rotated with same rotation degree as new axes.
RESULT OF “CAR SOUND MAP” Figure 5 shows calculated “car sound map” in acceleration condition.

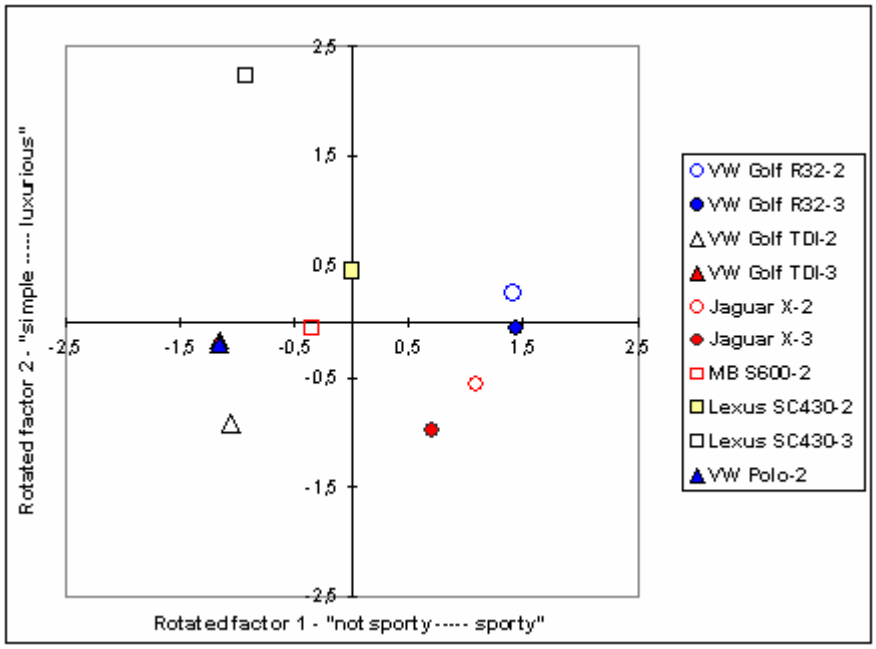


Figure 5: *Car sound map*

3.2 Discussion – Sound classification by "car sound map"

Four groups could be categorised by car sound map. In figure 5, Jaguar X Type and VW Golf R32 showed two sporty groups. VW Golf R32 and Jaguar X Type had different characteristics in an axis "luxurious – simple". Impression of "luxurious" was additional affect on categorising sporty cars, which could be different contents in frequency.
Two another groups consisted of "luxurious cars" group and "others group". Lexus SC430 at 3rd gear showed really high luxurious sound.
Engine sound in acceleration would be clearly categorised by two axes.

4 FAVORITES OF DIFFERENT CAR OWNERS

4.1 Evaluation by three car owner groups

Do Porsche owners and Mercedes S-Class owners prefer the same car sounds? Noumura and Yoshida [5] reported intercultural differences in the preference of sporty and luxury sounds. Here preference differences of three car owners groups, namely "sporty", "luxurious" and "classic" were investigated.
SUBJECTS 45 normal hearing subjects were divided into 3 groups according to the type of cars they own. (Table 4)

Owner groups	Owned cars
Sporty (n=15)	Ferrari 355 GTS, Porsche Boxster, Porsche Carrera 4S, Lotus Elise, VW Golf R32, BMW M3, Z3, Z3 M Coupe, Z3 M Roadster, Z8, Audi RS4, S3, TT
Luxurious (n=14)	Mercedes-Benz S-Class, Mercedes-Benz CL 500, BMW 7er, Audi A8, S8
Classic (n=16)	VW Golf, VW Passat, Ford Mondeo, Skoda Octavia, Opel Omega, Opel Vectra, Mercedes-Benz E-class, Audi A4, Audi A6, BMW 5er

Table 4: *Cars in each of the three groups of car owners*

STIMULI 12 test signals were based on binaural measurements of interior car sounds at driver's ears. Sounds were recorded from 6 cars (Audi A8, Jaguar X type, MB S600, VW Golf R32, VW

Polo, VW Touran) at two driving conditions: constant speed at 70 km/h and wide open throttle (WOT) acceleration at 3rd gear.

EXPERIMENT SET-UP A computer program controls the presentation of the test signals. The stimuli were played back via a sound card, an amplifier and headphones in a quiet office room. The sounds were presented at original loudness once and each subject listened to all sounds in random order. Three unipolar rating scales with five steps – the extremes were denoted by "very" and "not at all" – were used with the adjectives "sporty", "luxurious" and "classic" in German. The subjects had to circle the appropriate scale value.

4.2 Results and discussion

Figure 6 and 7 show evaluations of engine sounds by different car owner groups.

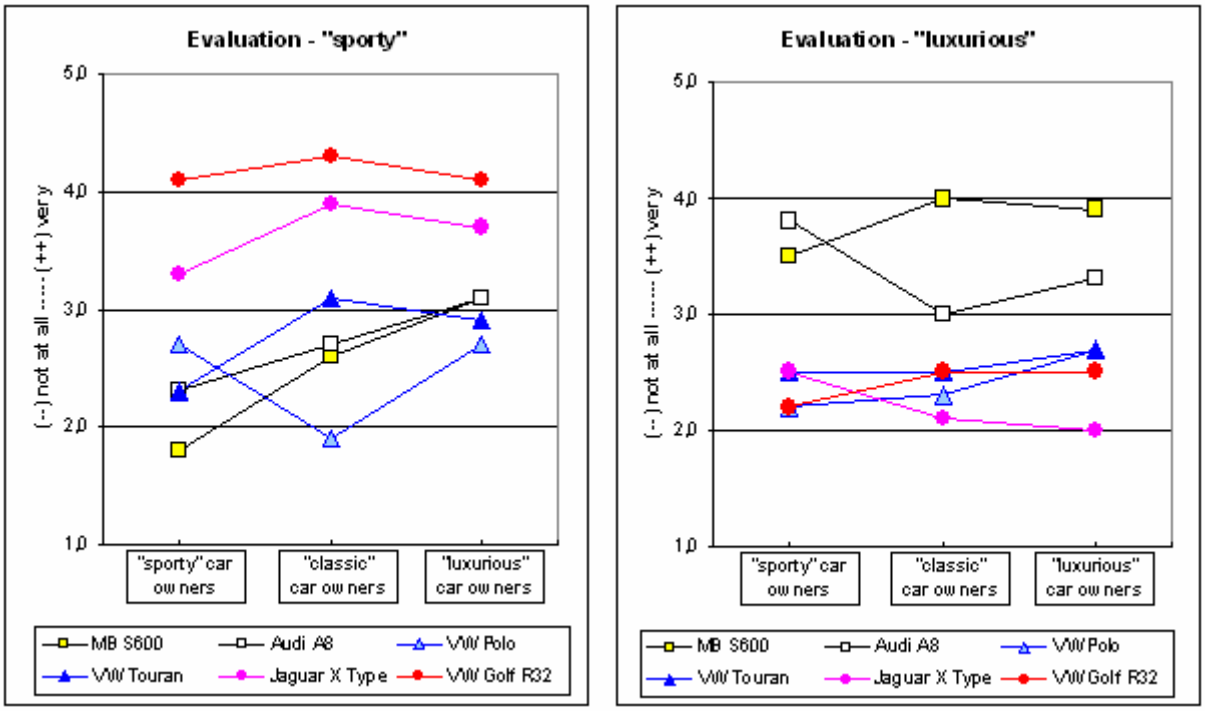


Figure 6: *"sporty" and "luxurious" evaluations by different car owners*

The ranges of the "sporty" evaluation (figure 6, left panel) differed between car owner groups. Obviously the rated differences in sportiness between the judged car sounds were larger for car owners of "sporty" and "classic" cars than for "luxurious" car owners. Additionally the "sporty" difference between Jaguar X type and VW Golf R32 was larger for "sporty" car owners than for the other two groups.

Essentially the "luxurious" car owners only made a difference between two clusters of cars, one consisting of VW Golf R32 and Jaguar X type (rated highest) and the rest. Against general trend the sportiness of VW Polo was rated rather high by "sporty" car owners.

On the other hand, "luxurious" and "classic" car owners showed higher sensibility to test signals in "luxurious" dimension (figure 6, right panel) than "sporty" car owners. Sporty car owners made a difference between two clusters of cars, one consisting of Audi A8 and Mercedes-Benz S600 (rated highest) and the rest. "Luxurious" car owners judged that Jaguar X type was not "luxurious" at all.

In "classic" evaluation "classic" car owners showed the highest range of judgment compared to the other groups. (figure 7, left panel) Against general trend, a distinct difference between "classic" and "luxurious" car owners was in the ratings of Mercedes Benz S600. "Luxurious" car owners

evaluated that Mercedes Benz S600 was not “classic”. Figure 7, right panel, showed high negative correlation between “classic” and “sporty” judgment for “classic” car owners.
In conclusion, one can observe that the sensibility of different car owner groups is the highest for the perceptual dimension that coincides with type of car they own.

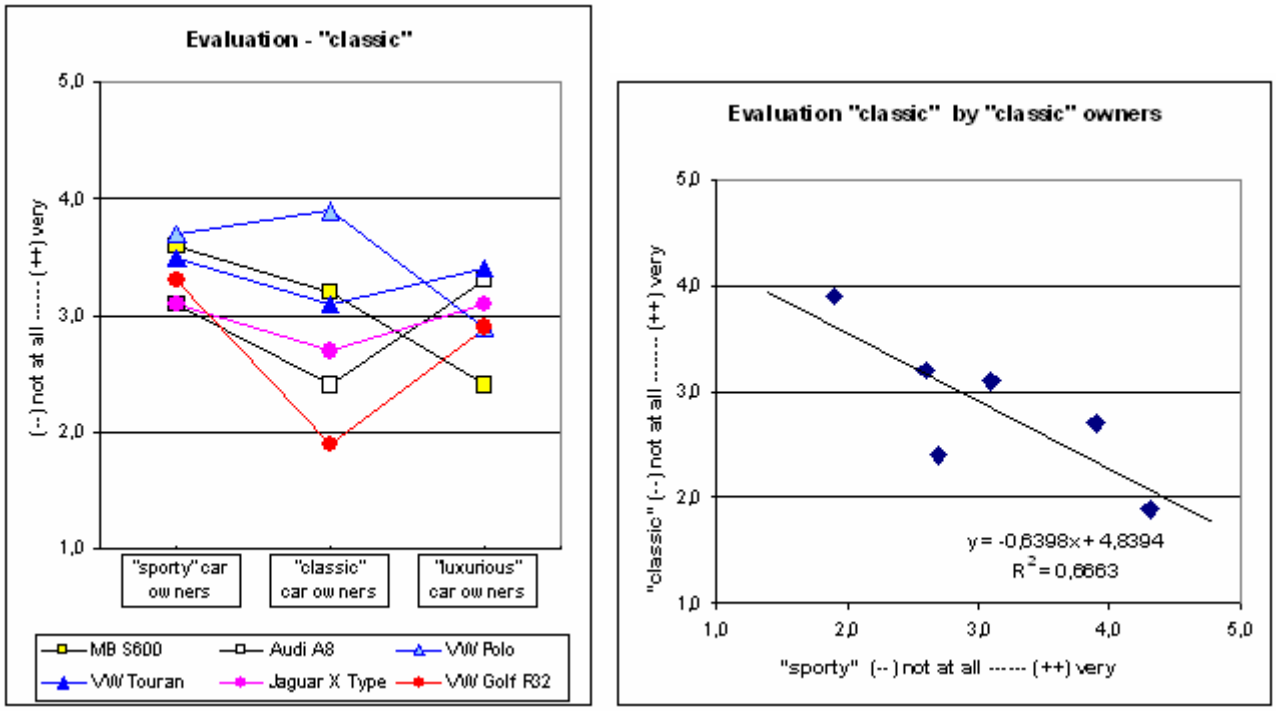


Figure 7: *“classic” evaluation*

5 SUMMARY

Perceptual space of engine sound is clearly dependent on driving conditions. When cars accelerate, acoustical impression “sporty” is independent from “luxurious” in the perceptual space.

It turns out that car owners’ preferences on car sounds are strongly influenced by the type of car they own. In general they are most sensible to the acoustical dimension that is typical for their own car.

ACKNOWLEDGEMENTS

I gratefully thank Ms. Keuser in Spiegel Institute to help listening tests with different car owners.

REFERENCES

[1] S. Namba and S. Kuwano, Method of Psychological Measurement for Hearing Research, Corona Publishing Co., LTD, 1998, pp. 121–125. (in Japanese)
[2] F. Brandl, W. Biermayer and S. Thormann, “Objectives description of the required interior sound for exclusive passenger cars”, DAGA 2000, Oldenburg.
[3] T. Wakita, “Objective Rating of Vehicle Sound Quality”, Toyota R&D review, vol. 27, No.3, 1992 (in Japanese)
[4] A. Crewe, G. Dunne and R. Williams, “NVH Target Management Closses the Product Evaluation Loop”, Sound and Vibration, 2000, http://www.mts.com/nvd/pdf/20000426.pdf
[5] K. Noumura and J. Yoshida, “Perception Modeling and Quantification of Sound Quality in Cabin”, SAE technical paper series, 2003
[6] N. Kubo, V. Mellert, R. Weber and J. Meschke, “Engine sound perception”, DAGA 2004, Strasbourg