Engine sound perception – Apart from so-called engine order analysis

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Introduction

Engine sound plays an important role on car quality. Thus, there are many researchers investigating car sound quality. However, it is not clearly understood how psycho-acoustical approaches relate to usual analysis of car manufacturers, like order analysis, in particular related to meanings of "sporty" and "luxurious". In this paper meaning of sporty and luxurious impressions are firstly investigated, and time dependent spectrum of an engine sound is analysed and related to these adjectives in the next step.

Assessment of engine sound

Known evaluation of car sound and the impressions "sporty" / "luxurious"

It is well-known that car sound is characterised psycho-acoustically by three factors, often described as "powerful", "pleasant" and "metallic". However, it is of interest for car manufacturers to understand "sporty" and "luxurious" impressions in terms of psycho-acoustic parameters as well. Some researchers conclude the psycho-acoustical three factors are not relevant for car sound impression. [1] [2] Therefore, the presented investigation focuses on the relationship between the three factors and the impressions "sporty" and "luxurious".

Semantic differential – analysis of adjectives

Two subjective tests are conducted in order to get insight into the subjective meaning of engine sound in different running conditions.

Subjects: 17 people of age 24-40 years old (mean: 28.6), 15 Germans – 2 non-Germans, 13 male – 4 female

All subjects have normal hearing. Non-German speakers live in Germany at least 4 years and have good understanding of German language.

Apparatus: A computer program controls the presentation of the test signals. The stimuli are played back via a 16-bit sound card and delivered to headphones and subwoofers.

Procedure: Each subject listened to all sounds in random order. With a questionnaire of 15-16 bipolar adjective pairs in German 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.

Stimuli: All test signals are based on measurements of interior car sound at driver's ears. Two running conditions, WOT acceleration and constant speed are separately evaluated. Both tests present 10 signals. Sounds of 6 cars are recorded in 2nd and 3rd gear for acceleration. Sounds of same 6 cars are measured in constant speed at 50 and 100 km/h.

Result - factor analysis

Table 1 and 2 give the result of the factor analysis for the most important adjective pairs. The factors are easily identified in the meaning as "pleasant", "metallic" and "powerful". These three adjectives are set by definition.

adjective pair	Factor 1 "pleasant"	Factor 2 "metallic"
dynamic – calm	0.984	0.681
quiet – loud	-0.980	-0.614
rough – smooth	0.970	0.663
powerful – powerless	0.967	0.440
alive – paralysed	0.956	0.612
consistent – not consistent	-0.949	-0.714
pleasant – annoying	-0.934	-0.689
sporty – not sporty	0.896	0.551
strong – weak	0.879	0.179
luxurious – simple	-0.870	-0.795
expensive – cheap	-0.821	-0.840
dark – bright	-0.497	-0.988
shrill – not shrill	0.734	0.974
metallic – dull	0.559	0.953
high – low	0.391	0.951
Variance (%) (Cumulative)	76.9	16.1 (93.0)

Table 1: factor analysis – constant speed

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
consistent - not	-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
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
shrill – not shrill	0.156	-0.750	0.729
Variance (%) (Cumulative)	46.9	30.5 (77.4)	16.8 (94.2)

Table 2: factor analysis – acceleration

Note: All adjectives are translated into English for the tables

Discussion

The two different conditions show a perception space of two and three dimensions, respectively, indicating that the test persons assess the sound differently for accelerated and constant speed motion. In the case of acceleration the dimension "powerful" includes "sporty" and the dimension "pleasant" includes "luxurious". 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" and at all, i.e. it is linear independent from this assessment and thus located perpendicular to "sporty" in the space of perception.

Objective parameter

"Sporty" in acceleration – Slope between frequency and time

In order to understand objective parameters relative to "sporty", a pre-test was conducted with 8 cars in WOT acceleration by same procedure as previous test. The slopes S_{ft} between frequency and time in main engine order were calculated.

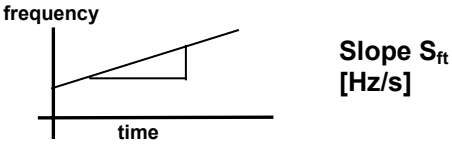

Figure 1: Slope in main engine order

Figure 2 shows a good correlation of S_{ft} with "sporty" provided, one special car sound (marked by arrow) is not taken into account. This special sound is noticeably quieter subjectively and also in level. (57.2 dB(A), while the others range from 62.0 to 75.1 dB(A)). Therefore, it is supposed that additionally to $S_{ft,}$ loudness contributes as a significant parameter. To prove this assumption another 11 accelerating sounds are correlated with S_{ft} slope and level. Figure 3 shows a good correlation. (R-square: 0.78)

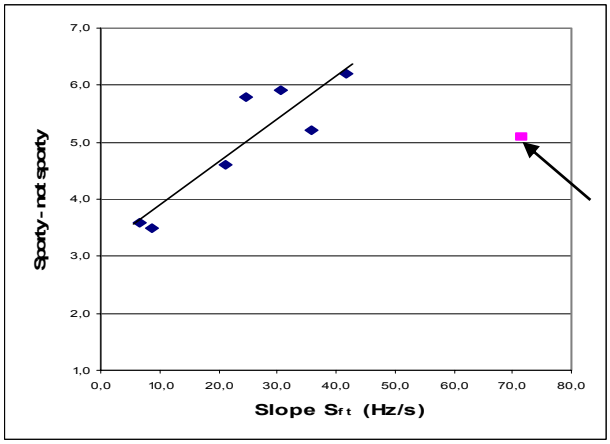

Figure 2: Correlation of "sporty" only with slope S_{ft}

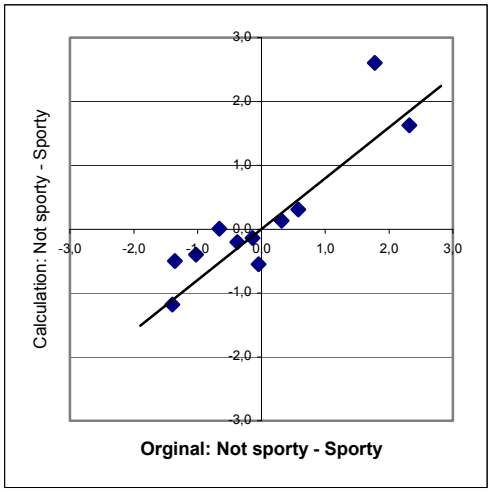

Figure 3: Correlation of "sporty" with combined level [dBA] and S_{ft}

"Luxury" in constant speed – Loudness and Roughness

To understand "luxury", a test is conducted at constant speed, 70km/h, by same procedure as in the pre-test.

Car	Loudness (Sone)	Roughness (Asper)	Luxurious
Lexus LS430	5.1	0.2	6.6
Nissan Cima	10.8	0.5	6.4
Mercedes-Benz S400	11.7	1.0	4.1
Jaguar X-Type	15.6	1.0	3.8
Seat Leon Cupra R	17.3	1.4	3.0
Alfa Romeo 156	18.6	1.4	2.6
VW Golf TDI	15.2	1.1	2.6

Table 3: "Luxury" in constant speed

Quite a big difference is observed in the luxusiours impression between Nissan Cima and Mercedens-Benz S400, although only the roughness is different.

Summary - "Sensory formation"- Sound formatting in time and frequency

The following assumptions are drawn from the preliminary tests;

- "sporty" is a function of S_{ft} and loudness
- "luxurious" is a function of loudness and roughness

Slope S_{ft} and roughness are time-related properties of the acoustic signal, while loudness reflects an average impression in the present analysis. The investigation of sound quality must therefore take both time dependent and spectral parameters into account.

References

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