The Semantic Space of Vehicle Sounds - An Approach to Develop a Semantic Differential in View of Customer Perceptions

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Abstract

Sound quality evaluation of the vehicle sound is a complex process. Physical measures are not sufficient to describe and understand this process and they can only give superficial cues. Psychoacoustical parameters and measurements also do not allow a general description of the vehicle sound quality. The quality evaluation of the customers is based on their perception, interpretation and expectations. The aim of this study is to generate the semantic space of vehicle sounds. In other words, a number of attributes relating to the perception and quality of vehicle sound will be elicited. This semantic space will be the basis of the development of attribute scales (Semantic Differential). Therefore our aim is to find the common descriptive language of the customers which is appropriate for the vehicle sound quality evaluation. An approach was developed and applied in this study. The steps of this approach include a thinking aloud test (free verbal remarking interview), the evaluation of the terms according to their suitability in describing acoustically perceptible vehicle properties by all subjects, testing the understandability of the attributes for all subjects, control the completeness of the semantic database to describe the vehicle sounds conducting a similarity experiment, testing the relevance and the redundancy of the attributes. At the end of the investigation eight different sets of attributes were developed for eight different driving conditions. Each set contains 18 to 36 attributes.

Index Terms: Vehicle sounds, semantic differential, perception.

1. Introduction

We judge a product as being of high quality when all our expectations are met or even exceeded, when we perceive it as a closed harmonic entity. Quality features of industrial products are, of course, functionalism, safety, usefulness, but there are also aesthetic or emotional aspects. These quality features have to be designed in such a way that they unambiguously direct at the product, which means that all perceived quality features have to comply with the general product idea. In other words: the design goal is to create an object which – when it becomes an object of perception – stimulates and satisfies customer interests. Customer interests are satisfied when the designed product leads to a harmonic perceptual entity.

Sound quality evaluation of the vehicle sound is a complex process. Physical measures are not sufficient to describe and understand this process and they can only give superficial cues. Psychoacoustical parameters and measurements also do not allow a general description of the vehicle sound quality. The quality evaluation of the customers is based on their perception, interpretation and expectations. The aim of this study is to generate the semantic space of vehicle sounds. In other words, a number of attributes relating to the perception and quality of vehicle sound will be elicited. This semantic space will be the basis of the development of attribute scales (Semantic Differential). Therefore our aim is to find the common descriptive language of the customers which is appropriate for the vehicle sound quality evaluation.

In the majority of empirical research on vehicle sound quality, the semantic spaces were investigated using trained expert listeners or experts (vehicle acousticians). They have decided which attributes should be used in the semantic differentials [1,2,3]. The advantages of the trained expert listeners are that they can provide usable data with relatively few experimental iterations and identify small differences between stimuli [4]. However the big disadvantage is that the knowledge, the taste, the interpretation and the expectations of expert listeners can strongly differ from the key customer group of the product. This point is particularly important, if we think about the wide variety of vehicle types and models. In this study the semantic space of vehicle interior and exterior sounds was investigated using average customers who have no technical background or specific acoustic knowledge.

A possible methodology to elicit attributes is the thinking aloud (free verbalization) method [5]. In this approach, the people are asked to talk during performing a task or a process (In our case, the task is the evaluation of vehicle sounds). The resulting verbal protocols should be analyzed and interpreted to obtain the fundamental issues of the processing action.

In recent years, the repertory grid technique (RGT) and the perceptual structure analysis (PSA) were also used to elicit auditory attributes in the context of multichannel reproduced sound [4, 6]. RGT consists of two parts: elicitation of verbal descriptors and rating of the descriptors. In the first part, the subjects are presented with triads of the stimuli and asked to indicate which of the three sounds differed most from the other two. He or she is then asked to describe ways in which two of the stimuli are alike and different from the third. In the second part, the subjects are asked to give a rating for each of the stimuli according to each of the constructs elicited in the previous part. In PSA approach, the subjects are presented again with triads of the stimuli and asked to consistently identify features in the sounds, without having to name them. This approach requires that the subject should have a clear idea of the features before proceeding with this task [6]. Therefore an extensive training session is necessary.

In this study, the thinking aloud technique was applied. One advantage of free verbalization is that no stimuli have to be compared directly with each other. Another advantage is that the duration of the experiment in the thinking aloud technique is mostly shorter than other techniques. Two steps of our approach to obtain a common set of attributes “thinking aloud technique” and “suitability check” are similarly applied in the investigations [8, 9]. In this study, the criteria “the understandability check of the attributes for all subjects” and “the completeness check of the database” were tested and a similarity investigation was conducted differently from previous investigations.

2. Elicitation of Verbal Descriptors

For the investigation, representative vehicle types and real-life driving situations were selected. The chosen driving conditions depending on the listener's location were:

- Interior
  - "engine start",
  - "idle",
  - "acceleration (tip-in)"
  - "passing maneuver"
- Exterior
  - "engine start"
  - "idle",
  - "accelerated pass-by: slow and fast"

A total of 17 subjects (10 males, 7 females) participated in the first experiment. The binaurally recorded sounds of 24 cars in eight driving conditions from different brands with different motorization were presented to the subjects.

The context is an important aspect for this kind of experiments. Therefore a training session was conducted. In the training phase, which took about 15 minutes, the driving conditions were verbally and with visual materials (recording of the driving condition, picture of the driving route) explained to the subjects.

In the experiments, participants are asked to describe all the auditory perceptible impressions during and after listening the vehicle sounds. This resulted in over 650 different descriptive terms. The terms from different perception layers which were used by participants can be categorized into four main categories:

- Signal related terms without any emotional content: e.g. loud, dull and spluttering
- Terms related to physical properties of the vehicle: small, new, luxurious, light
- Emotional terms: threatening, importunate, aggressive
- Association with vehicle type or label: mini transporter, turquoise, taxi, luxurious, sporty

These main categories can be splitted into 17 detailed groups (Table 1). Some of the terms can be categorized into more than one group.

Some participants have also named different vehicle brands (70 times). Some of the terms, which were used by participants, were in complex nature and do not present a clear unmistakable impression. Therefore an interview was conducted with the participants after the free verbalization experiment. In this interview the participants were asked if they can define what they mean by the terms which have complex nature. For example one of the participants used the term "taxi" for some sounds. In interview, we noticed that the subject experienced diesel vehicles as taxi passenger only. Therefore she/he associates diesel typical vehicle noise with taxis and uses the term "taxi". It was also very interesting that some subjects could associate some colors with the vehicle sounds (black, turquoise, etc.). The interview results showed us that most of them make an association between color and the frequency content of the vehicle sound unconsciously. Some participants have an association between the color black and limousines. In some cases it was not possible to reconstruct the relationship. Particularly variation of the emotional terms, which were used for the same sound by different subjects, was observable. In some cases the term "exciting" and the term "bothersome" was used for same sound by two different participant groups. Some participants used the term "sporty" and some other "not comfortable" for same vehicle sound.

Table 1. *Main categories for descriptive terms*

1	Timbre	dull, low-frequency, metallic
2	Power	high-powered, strong, strenuous
3	Intensity	loud, moderate, smooth
4	Regularity	constant, jerky, steady
5	Pleasantness	bothersome, pleasant, coherent
6	Dimensions	small, spacious
7	Onomatopoeia, nature	humming, whining, booming
8	Distinctive features	unremarkable, characteristic, extreme
9	Durability	solid, qualitative, kaput
10	Onomatopoeia, general	sibilance, rattling, squeal
11	Age	new, second hand, age-old
12	Sonority	insulated, clear, solid
13	Image	suitable for daily use, sporty, functional
14	Price	cheap, valuable, affordable
15	General product features	turbo, good, cost-saving
16	Technical associations	Turbine, turbo, diesel
17	Vehicle type	roadster, transporter, gasoline

The aim of this study was to acquire a common set of attributes for evaluating by all panel members, instead of obtaining only individualized attributes. For this reason, a further test was carried out whereby the terms were evaluated according to their suitability in describing acoustically perceptible vehicle properties by all panel members. For the suitability evaluation a quasi-continuous Rohrmann scale (from "not suitable" to "extremely suitable") was used. A graphical user interface was implemented in Visual Basic. The order of the terms was randomized between subjects. Some of the terms were presented two times to check the reliability of the participants' responses.

The results of the suitability investigation are outlined in Figure 1. The results show that 688 terms are almost equally distributed on the suitability scale. A reduction of the terms was made on the basis of the suitability judgments: excluding all adjectives, which were rated less than very suitable (75% of maximum suitability value, red line in Figure). 144 terms which obtained high suitability scores are chosen for further investigation.

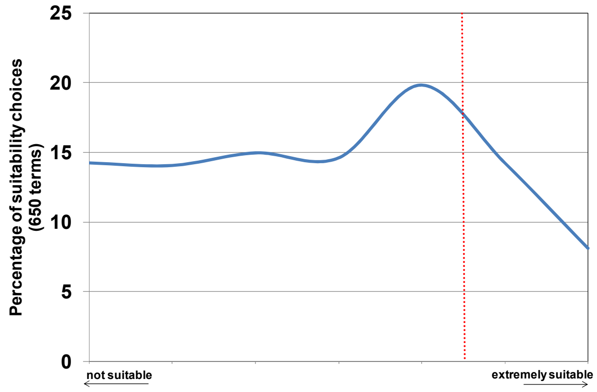

Figure 1: *The distribution of the Suitability ratings of 688 terms on the suitability scale.*

The 144 terms are studied to determine the antonyms (opposite pole) of the terms. Most of the opposite poles of terms were included already in the list of 144 terms. Additionally an interview was conducted and the participants were asked to name the antonym of the terms. Then the participants evaluated the antonym pairs according to their suitability as opposite verbal descriptors using a quasi-continuous Rohrmann scale (from "not suitable" to "extremely suitable"). Clear antonyms can be found in about 46 % of the cases. It was not possible to find opposite pairs of onomatopoeic terms. Moreover obtained adjective pairs are not always bijective.

To obtain the common set of attributes, our approach was to test the further criteria as:

- the understandability of the attributes for all subjects,
- the redundancy of the attributes,
- the completeness of the semantic database to describe the vehicle sounds and
- the relevance.

To check the understandability, a further test was carried out whereby the terms were evaluated according to two criteria. Panel members (41 subjects) should sort the terms, which do not associate an explicit meaning for them, or which are irrelevant for the driving condition. At the end of the evaluation, the terms, which do not have explicit meaning for the subjects, or which are not suitable for the driving condition, were excluded.

To check the completeness of the database to describe the vehicle sounds, a similarity investigation and a semantic differential investigation were conducted. In the dissimilarity investigation, listeners are presented with sounds in pairs, and are asked to rate the dissimilarity between them using a quasi-continuous scale. The advantage of the similarity investigation is that the method does not require the use of source-related linguistic labels. Therefore the investigation is freed from the linguistic capabilities of the subjects. The dissimilarity distances between the sounds are the results of the perceived differences regarding the descriptive terms (Figure 4). This relationship can be described as follows;

$$\delta_{i,j} = a*(t_{1,i} - t_{1,j}) + b*(t_{2,i} - t_{2,j}) + c*(t_{3,i} - t_{3,j}) + \dots \quad (1)$$

where $\delta_{i,j}$ is the dissimilarity distance between the sound "i" and the sound "j", $t_{m,i}$ is the rating for the descriptive term "m" of the sound "i", a/b/c/… are the weightings of the descriptive terms in the dissimilarity judgments.

In the next step, a Semantic Differential Test was carried out using descriptive terms which were determined in this study. The sound database consisted of interior and exterior sounds of 36 cars. The subjects assessed the intensity of their association on a quasi-continuous five-point Rohrmann scale. Two different scales were used for the terms. The scale, which is shown in Figure 2, was used for the terms which do not have any clear opposite pole. The scale, which is shown in Figure 3 was used for the terms which have a clear opposite pole.

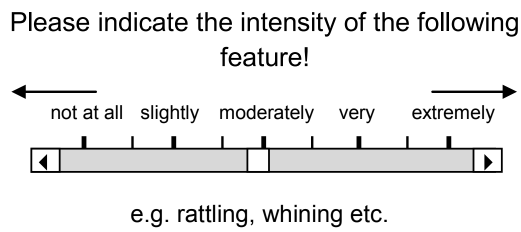

Figure 2: *Rohrmann scale for the terms without opposite pole.*

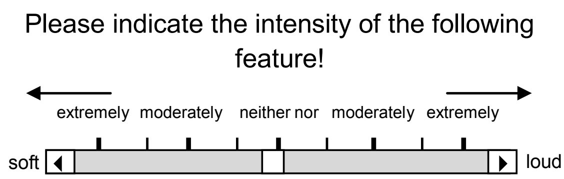

Figure 3: *Rohrmann scale for the terms with opposite pole.*

To check the redundancy of the attributes, a cluster analysis was conducted on semantic differential data (The squared Euclidean distance). The cluster analysis provides important indications about the similarity of the terms. The terms, which show big similarities with each other, were excluded from the databank, such as hammering, buzzing, screaming. Terms, which obtained maximum suitability rating, remain in the databank and others will be excluded.

The repeatability of the subjects' judgments shows a robust meaning association. To check the repeatability, four randomly selected attributes from the databank were asked two times to the subjects in semantic differential investigation. To avoid the short-term memory effects, the terms were repeated in two separate sessions. The results of the repetition show that the judgments of the subjects aggree with their previous judgments. Maximum deviation of the means is not higher than 8 %.

In the next step the results of the similarity investigation and semantic differential investigation were compared to each other to check the completeness of the database. The weightings of the individual terms in the dissimilarity judgments are dependent to the driving conditions. Therefore the comparison of the results was done for each driving condition separately. Determination of the weightings for the extreme conditions (70 % < similarity rating of stimuli or similarity rating of stimuli < 30 %) is much easier than moderate conditions (35 % < similarity rating < 65 %). An exemplary comparison is shown in Figure 4. The overall comparison results show that the remained adjectives can describe the vehicle interior/exterior sound space successfully. Dissimilarity ratings of the stimuli can be explained with tight tolerances, which are smaller than 20 %, by semantic differential terms.

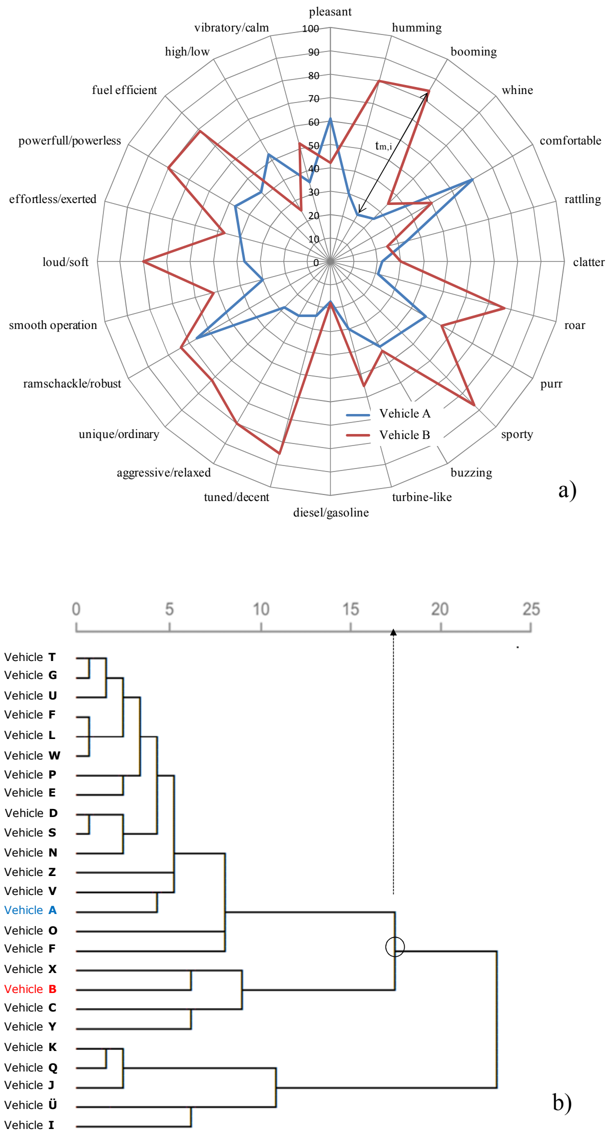

Figure 4: *Completeness check is demonstrated using the representative investigation results of two vehicles. a) The results of the SD, b) The similarity cluster.*

On the basis of the above-mentioned investigations, eight different sets of attributes were developed for eight different driving conditions. Each set contains 24 to 36 attributes. These sets are summarized in two main groups for interior and exterior noise (Table 2 and 3), because of their comparability.

Table 2. *The set of attributes for the exterior vehicle noise.*

Exterior noise	
The terms, which have antonyms	
low (tief)	high (hoch)
powerless (schwach)	powerfull (stark)
soft (leise)	loud (laut)
calm (vibrationsarm)	vibratory (vibrierend)
relaxed (entspannt)	aggressive (aggressiv)
ordinary (gewöhnlich)	unique (besonders)
robust (robust)	ramshackle (klapprig)
decent (dezent)	tuned (aufgemotzt)
high fuel consumption (verbraucht viel sprit)	fuel efficient (sparsam)
gasoline (benziner)	diesel (diesel)
exerted (angestrengt)	*effortless (mühelos)*
overtorqued (überdreht)	*smooth balanced operation (laufruhig)*
slow (langsam)	*fast (schnell)*
mini, small (mickrig)	*puissant (mächtig)*
The terms, which do not have clear antonyms	
pleasant (angenehm)	
humming (brummen)	
booming (dröhnen)	
whine (heulen)	
comfortable (komfortabel)	
rattling (rasseln)	
clatter (rattern)	
roar (röhren)	
purr (schnurren)	
sporty (sportlich)	
buzzing (summen)	
turbine-like (turbinenartig)	
troublesome (lästig)	
obtrusive (penetrant)	

Table 3. *The set of attributes for the interior vehicle noise.*

Interior noise	
The terms, which have antonyms	
low (tief)	high (hoch)
loud (laut)	soft (leise)
calm (vibrationsarm)	vibratory (vibrierend)
relaxed (entspannt)	aggressive (aggressiv)
ordinary (gewöhnlich)	unique (besonders)
decent (dezent)	tuned (aufgemotzt)
robust (robust)	ramshackle (klapprig)
high consumtion (verbraucht viel sprit)	fuel efficient (sparsam)
gasoline (benziner)	diesel (diesel)
weak (schwach)	*strong (stark)*
steadily (kontinuierlich)	*irregular (unregelmäßig)*
muffled (gedämpft)	*reverberant (hallend)*
The terms, which do not have clear antonyms	
pleasant (angenehm)	
humming (brummen)	
booming (dröhnen)	
whine (heulen)	
comfortable (komfortabel)	
rattling (rasseln)	
clatter (rattern)	
roar (röhren)	
purr (schnurren)	
sporty (sportlich)	
buzzing (summen)	
turbine-like (turbinenartig)	

3. Discussion and Conclusions

The results show that adjective sets for interior and exterior noises have strong similarities. Particularly signal related terms are equal in two sets. There are some additional (or different) emotional attributes in exterior noise set, such as exerted and troublesome. Some vehicle related terms, such as puissant and fast, appear only in exterior noise set. However the terms like reverberant, which are related to the acoustical condition of the vehicle interior, can be found in the interior noise set as expected.

In this study, the thinking aloud technique proved a useful technique to elicit verbal descriptors. The authors consider the ideas behind this investigation as a valid starting point for designing new investigations aimed at eliciting semantic space of sound events.

4. Acknowledgements

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