DELIVERABLE 2.8

CONTRACT N°	**TIP4-CT-2005-516420**
PROJECT N°	**FP6-516420**
ACRONYM	**QCITY**
TITLE	**Quiet City Transport**
Subproject 2	**Perception of Vehicle Noise Sources**
Work Package 2.2	**Subjective Perception of Noise Sources**
	Ranking of Noise Sources with Respect to Noise Perception
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Date of issue of this report	**02.08.2006**

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PROJECT START DATE **February 1, 2005**
DURATION **48 months**
Project funded by the European Community under the SIXTH FRAMEWORK PROGRAMME
PRIORITY 6
Sustainable development, global change & ecosystems

This deliverable has been quality checked and approved by QCITY Coordinator
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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

The following report describes the work done and results gained in WP 2.2.2 during the months 13 to 18 of QCITY.

The main objective was the assessment of the subjective perception of single pass-by sounds to gain a further evaluation method of sounds beside the dB(A). The perception data was used to develop an quantitative description of the annoyance effect of single pass-by noise and it was tried to define an dB(A) equivalent (bonus / malus) for the difference in annoyance between certain vehicle groups (e.g. vehicles with otto or diesel engines).

This deliverable describes the generation of the quantitative annoyance description including listening tests, sound analyses, statistical analyses and validation. Further, preliminary results of the bonus / malus considerations are presented.

0.2 STRATEGY USED AND/OR A DESCRIPTION OF THE METHODS (TECHNIQUES) USED WITH THE JUSTIFICATION THEREOF

For the assessment of the subjective perception listening tests had to be conducted. A combined scaling and ranking method was chosen for the design of the listening tests, since it is very convenient for the test individuals (TI) and generates stable and reliable evaluations. Unfortunately, large numbers of sounds cannot be evaluated together with this design; for those cases the classical single scaling was applied. The evaluation scale is derived from the Rohrmann intensity scale.

The selection of the relevant acoustic parameters was done with focus on the objective description of sound characteristics influencing the subjective perception. Therefore, the comments of the TI[1] were used to identify important sound characteristics and acoustic parameters representing these characteristics were compiled. Further, typical parameters like SPL and SPL_{max} were considered too.

The evaluation data was analysed applying the principal component analysis (PCA) which is a statistical method for dimensionality reduction. It can identify common factors influencing the evaluations of the TI. To relate these factors to the selected acoustic parameters correlation analyses were conducted between the factor values and the sound parameters. Parameters highly and often correlated with the first or second factor calculated by the PCA were selected for the quantitative description of the annoyance. Based on the factor

[1] TI … test individual / test individuals, this abbreviation is used for the singular as well as for the plural form

weightings and linear regression calculations the weighting of the parameters was optimized.

Additional listening tests were conducted for validation purposes.

0.3 BACKGROUND INFO AVAILABLE AND THE INNOVATIVE ELEMENTS WHICH WERE DEVELOPED

A method for the calculation of an evaluation index (EI) was developed. The EI represents the subjective annoyance of pass-by noise of a single vehicle at a distance of 7.5 m. It can be applied to any time signal complying with these demands. Acoustic parameters influencing the EI are

- Relative Approach (RA): assessing diesel and engine noise by evaluating time and frequency patterns as well as tonal components
- 5% percentile of the loudness (N_5): assessing the subjective loudness of the pass-by vehicle noise
- 5% percentile of the sharpness (S_5): assessing annoying characteristics in the high frequency range, e.g. tire hissing

0.4 PROBLEMS ENCOUNTERED

The development of a bonus / malus system for certain vehicle groups proved to be too extensive when single pass-by sounds are considered. The investigations will be continued within WP5.12 where it is possible to evaluate and analyses traffic scenarios with specific mixtures of the vehicle groups.

0.5 PARTNERS INVOLVED AND THEIR CONTRIBUTION

HEAD acoustics (HAC) conducted the listening tests, analysed the sounds and performed the statistical calculations.

The final creation of the EI was also done by HAC.

0.6 CONCLUSIONS

It was possible to create a qualitative description of the subjective annoyance of pass-by sounds based on psychoacoustic parameters. These parameters are

- Relative Approach (RA): representing diesel and engine noise
- 5% percentile of the loudness (N_5): representing the subjective loudness
- 5% percentile of the sharpness (S_5): representing annoying characteristics in the high frequency range, e.g. tire hissing

It is more reasonable to carry out investigations about bonus / malus relations within 5.12 using traffic scenarios with vehicle groups rather than comparing pass-by sounds of single vehicles.

0.7 RELATION WITH THE OTHER DELIVERABLES (INPUT/OUTPUT/TIMING)

D2.1: Usage of compiled database

D2.2: Usage of compiled database

D2.9: Input of evaluation data

D2.10: Input of evaluation data

TrafficNoiseSynthesizer (WP2.2.3 & WP5.12): Input of calculation method for EI

1 INTRODUCTION

In WP2.1 a database for exterior pass-by noise of different transportation means – mainly passenger cars – was compiled during the first 12 months of QCITY[2]. This report describes the assessment and analysis of the subjective perception of the compiled pass-by sounds.

The psychoacoustic testing has two aims:

- the determination of quantitative interrelations between the annoyance of pass-by sounds and their psychoacoustic parameters
- the definition of bonus/malus values in dB for specific vehicle groups regarding their differences in annoyance

The principle procedure to gain the raw data for the analysis is very much the same. Selected pass-by sounds are presented to test individuals (TI), which have to evaluate the sounds regarding their annoyance. The assessed annoyance scores form the basis for all further analysis. The selection and combination of the pass-by sounds for the evaluation is done with respect to the two testing objectives respectively.

Quantification of annoyance

It is assumed that the annoyance of different driving situations depend on several different parameters. The annoyance of tire noise will depend on different parameters as the one of engine noise, since they are characterised by different time and frequency features. Therefore, the annoyance quantification of idle noise and pass-by noise at 50 km/h will be described differently also. The same applies for the comparison of vehicles, since their pass-by noise does not composes of tire and engine noise in the same way. Furthermore, the engine type probably affects the main acoustic parameters of its noise.

Bonus/Malus Values

To identify a dB(A) equivalent for the annoyance effect of different vehicle groups pass-by sounds of selected vehicles are presented at their original dB(A) level and – in an additional test set – at a adjusted dB(A) level. In a first step this adjustment is made rather arbitrarily, since yet no well-founded assumption about the bonus/malus values can be made. It is decided to adjust the dB(A) level to an equal level. Thus, a certain range of changes in level is realized and the data can also be used for the annoyance quantification.

[2] The measurements were performed in accordance to the ISO 362 at 7.5 m distance and 1.2m height. For further details about the data acquisition for the database see D2.1 and D2.2.

The annoyance evaluations will be analysed in terms of the dB(A) changes and different vehicle groups. Using the results of this analysis it will be possible to perform further listening test with selected level adjustments for defining the bonus/malus values.

Procedure

To assess the parameters for the driving situations and the vehicle types different test sets are composed:

- sets of one specific driving condition of different vehicles to compare the vehicle types and find descriptors for the respective driving situation
- sets of one specific vehicle in different driving situations to compare the driving situations and find descriptors for the respective vehicle
- sets of different vehicles in different driving situations for a analysis independent of vehicle and situation and for validation

The acquired data is statistically evaluated regarding the validity of the data. Therefore, the answers of the TI are compared by applying cluster analysis to the ranks and annoying scores. Hereby, outliers and the formation of groups can be identified. The samples of TI for the single test sets can be compared using the t-test method for independent samples.

The further analysis includes cluster analysis and principle component analysis (PCA). The calculated scores of the PCA are correlated with selected acoustic and psychoacoustic parameters to identify the main parameters influencing the subjective evaluations of the driving situations / single vehicles. With this, the evaluations of the single vehicles / driving situations could be explained in more detail, e.g. why a certain car was rated high or low.

Primarily, the acoustic parameters identified as relevant are used to create a calculation method for the representation of the subjective annoyance of pass-by sounds. Therefore, the acoustic parameters have to be combined in a way that reflects the influence of their perceptive equivalents on the evaluations. The final equation will calculate an evaluation index (EI) that provides information about the annoyance of a single pass-by noise without the necessity of listening tests. Hereby, the annoyance effect of vehicles or driving conditions can conveniently be analysed and compared.

In WP5.12 the gained experiences and knowledge about the perception of pass-by noise will be used to enhance and adapt the EI for filtered pass-by sounds (e.g. representing pass-by noise in flats or behind screenings) as well as traffic flow noise. This enhancement will give the possibility to evaluate urban traffic noise as it is present in cities and as it is perceived by residents and pedestrians.

The bonus / malus investigations give only preliminary results; therefore further investigations within WP5.12 are necessary. There it will be possible to analyse the differences of specific vehicle groups in the context of traffic flow noise as it occurs in urban cities. The advantage is that the comparison of specific vehicle mixtures is not as extensive as the one by one comparison of single vehicles.

The bonus / malus results gained within WP5.12 can be combined with the EI. Rules for the application of the bonus / malus will be defined also in relation to the EI or its components.

2 LISTENING TESTS

The design and execution of listening tests is one part of the psychoacoustic data acquisition. Therefore an adequate test procedure has to be developed and pass-by sounds have to be selected for the evaluation.

2.1 TEST PROCEDURE

As mentioned before, the test procedure for the two aims of the psychoacoustic evaluation is identical. Only the pass-by sounds have to be selected accordingly to the specific aim. But it is possible to reduce the effort by constructing test stets, that can provide input data for both tasks.

To keep the demands towards the TI rather low, the test procedure is designed in a way, that no specific skills are needed. The well known method of scoring on a perception scale and the possibility to listen to the pass-by sounds repeatedly facilitates the evaluation task for the TI[3]. The most important requirement a TI must fulfil is the criterion of sufficient hearing ability. That is, no more than 20 dB HL (hearing loss) at any frequency.

The complete test procedure consists of five steps:

1. Greeting and introduction
2. Audiometry
3. Instructions
4. Test
5. Interview
    a. Feedback
    b. Questionnaire

This test procedure is carried out with one TI at a time. Depending on the evaluation behaviour of the test person a complete test takes 30 to 45 minutes in total.

2.1.1 Greeting and Introduction

The TI is welcomed in a friendly manner to ensure a high level of open-mindedness. Nevertheless, the interaction with the TI should always be serious

[3] TI … test individual / test individuals, this abbreviation is used for the singular as well as for the plural form

and professional to avoid distractions from the test focus and unwanted "demand characteristics"[4].

At the beginning, the motivation of the test is described in connection with the EU project QCITY, the EU noise directive and the improvement of the noise situation in cities. By showing the positive aim and involving the TI into it, the motivation of the TI should be increased.

2.1.2 Audiometry

The test starts with a conventional audiometry carried out with the HEADAudiometer software of HEAD acoustics. The TI listen to discrete frequencies. The software slowly increases the intensity of the stimuli. If the TI is able to hear the sound, he presses a mouse button. The threshold for every frequency has to be confirmed during a second stimulus increase. Afterwards, the software changes the frequency and the procedure is repeated. The procedure has to be carried out twice, once for the TI's left and once for his or her right ear. After the audiometry the audiogram is shown and explained to the TI. All this is also explained to the TI before the audiometry starts.

To participate in the listening test the TI have to fulfil the criterion of a hearing loss less than 20 dB at any testing frequency. Thereby, the audiometry guarantees that only TI with a sufficient hearing ability take part in the investigation.

2.1.3 Instructions

After the audiometry the TI are instructed about the test procedure and their evaluation task. For gaining significant results it is essential that the TI understand all details and all questions have been clarified before the actual test. Therefore, the instructions are given in written and oral form. At first, the written instruction is handed to the TI for careful reading. Afterwards, the oral instruction starts with answering the questions of the TI concerning the written instructions. Then the test procedure is discussed in detail step by step. The TI are encouraged to ask without hesitation, if questions should arise.

The hypothetical situation of an open bus stop with vehicles passing by is described to form a common context for the TI. Their task is to evaluate the pass-by sounds regarding their annoyance effect.

A 9-point scale with the German verbal allocations of the Rohrmann scale for intensities is used for the evaluations. Figure 1 shows an English translation of this scale. The TI has to decide which of the nine categories represents its perception best. A category scaling is chosen since the applied SQuare software of HEAD acoustics does not allow continuous scales. The advantage of

[4] « Demand characteristics » describe the tendency of TI to change their behaviour because of being in a test situation, e.g. by presenting themselves in a special manner or by giving answers with respect to a imagined test objective.

the SQuare software is that the test procedure can be carried out easily and interactively by the TI on a computer screen using a computer mouse. The results are directly available and can be further processed with adequate software.

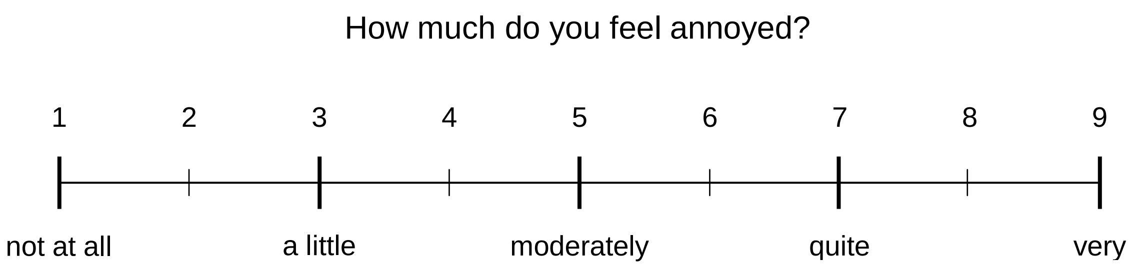


Figure 1: Evaluation scale

The pass-by sounds are presented in groups or sets. Mostly the evaluations method "category test with sorting" is used. Hereby, the sounds of one set are presented together and the TI can listen to the sounds arbitrarily often and compare them among one another. The annoyance evaluation is given on the corresponding 9-point scale. The software sorts automatically the sounds by the rating. Additionally, the order of the sounds can be changed with arrow buttons, especially if several sounds fall into one category and the TI wants to sort them. Figure 2 depicts the computer screen of the SQuare software for the method of category scaling with sorting. This method offers a high convenience for the TI by giving the opportunity to verify the own judgements. The results are more stable, use a wide range of the scale and are unaffected by representation sequences. As the evaluations will be given in relation to the sounds of the respective set, the comparability between the sets is limited and has to be considered separately.

To check the results of the "category test with sorting" some sound sets were retested with a pure category test, where the sounds are presented separately and no comparisons among them are possible.

A complete version of a listening test consists of four to six sound sets. The first one usually serves as a training sequence to familiarize the TI with the sounds and the evaluation method. After this training sequence the TI has the possibility to ask further questions, which occurred during the first evaluation.

Between the sets it is always possible for the TI to take a short break before continuing. This shall optimize the concentration and motivation of the TI for every single evaluation. There is no time limit for the evaluation. It is made clear, that it is crucial that the final evaluations represent the individual perception of the sounds. There are no right or wrong answers – only the individual perception.

Figure 2: Evaluation screen of HEAD acoustics' SQuare software for the category test with sorting

During the test the TI has always the possibility to communicate with the investigator via a microphone placed in the testing room.

2.1.4 Test

The listening test itself takes place in a small noise-reduced chamber (see Figure 4). The investigator monitors the whole test from an anteroom where he can watch the TI judgements on a second computer screen and listen to the microphone placed in the testing room. Hereby, he can immediately intervene if any problems or maloperation occurs.

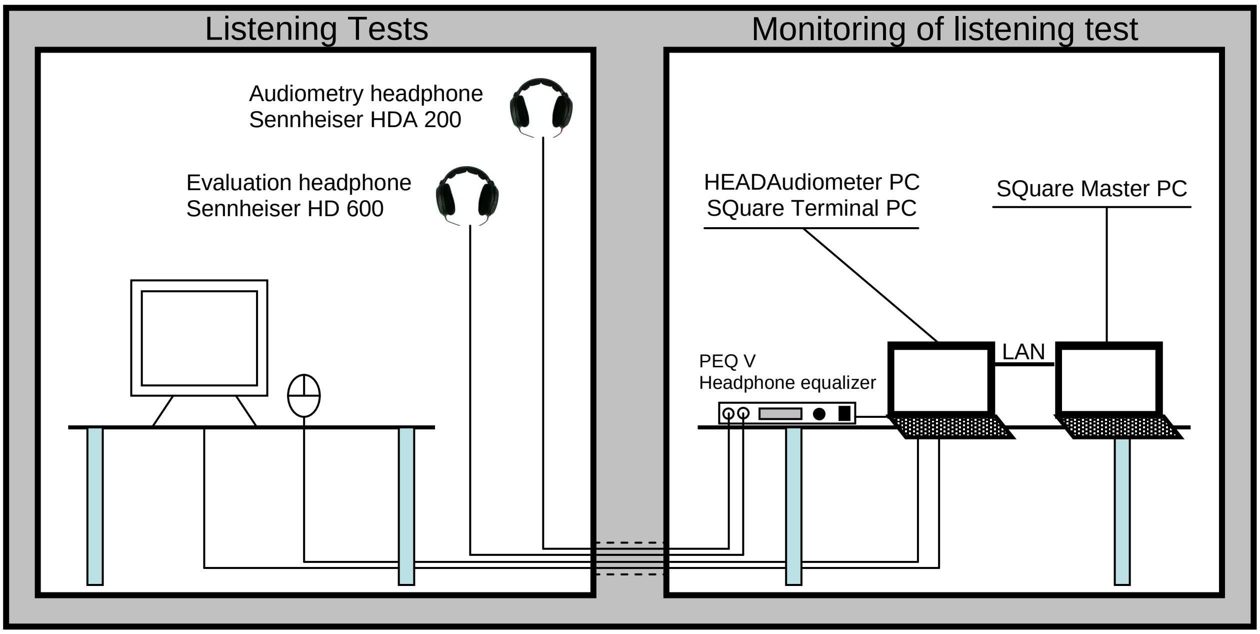


Figure 3: Experimental set-up

The TI carries out the listening test as described in the instructions. Mostly, no interference of the investigator is necessary during the evaluation.

After the evaluation is finished, the investigator joins the TI in the testing room and interviews the TI about the test and some personal data.

Figure 4: Testing room

2.1.5 Interview: Feedback and Questionnaire

During the interview the TI have the opportunity to express their feelings with regard to the test.

The first part of the interview deals with the test itself and how it was experienced by the TI.

Question: What do you think, what influenced your evaluations?

Question: How did you do your evaluations (e.g. first rating then comparing or first sorting then rating)?

These two questions about the individual evaluation method of the TI shall give hints about the evaluation background, give hints for the latter choice of psychoacoustic descriptors and can be used for the comparison of the TI.

Question: How difficult did you experience your evaluation task?

Question: Did you encounter any problems or irritation during the test?

Question: Would you participate in such a test again?

The answers to the three questions above give information about the demands of the evaluation task on the TI and thereby the quality of the ratings. But more important they give a feedback about the quality of the listening test. If the test is too difficult or irritating for the TI the results will not be reliable. In this case, the test design has to be modified accordingly. If the last question is answered with "No." it can be assumed that the motivation of the TI during the test was very low. This can be due to a way too long test, very annoying sounds, very difficult evaluations/comparisons, etc. Then the test design has to be changed fundamentally. Fortunately, this did not happen here.

The second part of the interview uses a small questionnaire to assess some personal data for statistical use. This questionnaire involves the following questions:

- How old are you?
- What is your gender?
- Do you have children? If yes, how many?
- Would you call yourself sensitive to noise?
- Do you feel annoyed by noise in your everyday life (e.g. at home or at work)?
- Are there any important noise sources in your neighbourhood / at your working place? If yes, what are they?
- Do you use regularly your car?

The answers are used to ensure a heterogeneous TI clientele. Additionally, it can be tried to relate certain evaluation patterns to individual parameters and noise history.

2.2 EVALUATION ITEM "ANNOYANCE"

The item "annoyance" is chosen for the sound evaluation because annoyance is the perception traffic noise provokes for residents and affected people. It is a relevant term concerning environmental noise.

The assessment of annoyance in the laboratory has yet to be questioned critically. It is a potential problem to evaluate the annoyance of a sound, when the evaluation and therefore the sound is within your main focus of attention. In general, things are annoying if they distract you from other activities or focuses. It would be possible to assess the pleasantness/unpleasantness of sounds, because here the focus of attention can be the sound. But such an evaluation item aims on a different dimension of perception compared to annoyance. The quality of the sound will be evaluated and not its annoying effect.

The instructions of the test procedure form a common context for the evaluation. It is a context every TI is familiar to and which can be related to the term annoyance for every TI. By this, it is possible to leave the sterile laboratory setting and evaluate the sound within an imaginary but realistic context.

After all, there is no negative feedback on the term "annoyance" or on the constructed context from the TI. This indicates that the TI are able to relate a meaning to the term 'annoyance' regarding the instructed setting.

2.3 SOUND SETS

During the planning of the listening tests it occurred that about 20 sound sets had to be conducted to get a sufficient data basis. The evaluation of all sets (with up to 13 sounds in each set) in one session cannot be expected by a TI. Therefore, the sets are arranged into so-called "versions" of the listening test. Each test version contains four to six sets. Hereby, the test length is kept below 30 minutes, which ensures a reasonable strain on the TI. Five versions – V1 to V5 – are applied. The configuration is listed in Table 1.

Table 1: Configuration of the sound sets for V1 to V5

V1	Set 1	intro	training sequence
	Set 2	const50	petrol and diesel vehicles at constant 50 km/h
	Set 3	med_acc30	petrol and diesel vehicles at a medium acceleration from 30 km/h
	Set 4	const30	petrol and diesel vehicles at constant 30 km/h
V2	Set 1	intro	training sequence
	Set 2	idle	petrol and diesel vehicles in idle mode
	Set 3	const50_equ	petrol and diesel vehicles at constant 50 km/h, equalized regarding dB(A)-level
	Set 4	stop_start	petrol and diesel vehicles at traffic light situation
V3	Set 1	intro	training sequence
	Set 2	med_acc30_equ	petrol and diesel vehicles at a medium acceleration from 30 km/h, equalized regarding dB(A)-level
	Set 3	const30_equ	petrol and diesel vehicles at constant 30 km/h, equalized regarding dB(A)-level
	Set 4	idle_equ	petrol and diesel vehicles in idle mode, equalized regarding dB(A)-level
V4	Set 1	intro	training sequence
	Set 2	petrol_veh	one petrol vehicle at const50, const30, med_acc30 and idle
	Set 3	diesel_veh	one diesel vehicle at const50, const30, med_acc30 and idle
	Set 4	const50_equ (repeat)	petrol and diesel vehicles at constant 50 km/h, equalized regarding dB(A)-level
	Set 5	med_acc30_mod	petrol and diesel vehicles at a medium acceleration from 30 km/h, modified
V5	Set 1	petrol_diesel_veh	sounds of V4 Set 2 and V4 Set 3 combined
	Set 2	const50_equ_cat	petrol and diesel vehicles at constant 50 km/h, equalized regarding dB(A)-level, pure category test
	Set 3	bm_const30	test concerning bonus/malus at const30
	Set 4	bm_const50	test concerning bonus/malus at const50
	Set 5	bm_const30_cat	test concerning bonus/malus at const30, pure category test
	Set 6	bm_const50_cat	test concerning bonus/malus at const50, pure category test

There are four different topics which the sound sets can be assigned to.

1. Weighting of vehicles

   To gain insights about the differences of various vehicles at the same driving condition, the exterior noise of six to eight gasoline or diesel vehicles is subject to evaluation. The considered driving conditions are const30, const50, med_acc30, idle and stop_start.

2. Weighting of driving situations

   Two sound sets compile the pass-by sounds of the four driving conditions const30, const50, med_acc30 and idle for a single vehicle respectively – one gasoline vehicle and one diesel vehicle.

3. Weighting of parameters

   Selected pass-by sounds are subject to specific acoustic modifications to evaluate the influence of single acoustic parameters. These modifications concern the dB(A)-level (for the bonus-malus-considerations), the sharpness and the low frequency share of the sounds.

4. Weighting, independent of the dB(A)-level

   The compilation of sounds is copied from “Weighting of vehicles”, but the dB(A) levels of the sounds are adjusted to the same value. The evaluations are used for the bonus-malus-considerations and illustrate the influence of the dB(A) on the perception.

2.4 STATISTICS

Each of the six versions is evaluated by up to 17 TI (minimum 11 TI). Each TI is subject to an audiometry to test their hearing ability. Thereby it is ensured that only persons with an “normal” hearing ability, which means no hearing loss higher than 20 dB for any testing frequency.

The average age of the TI is 35 years (minimum: 26 years, maximum: 56 years). 30 % of the TI are female, 70 % are male. One third of the TI has one or two children.

The majority of the TI (54 %) describe themselves as sensitive to noise, whereas only 22 % negate this question. 24 % of the TI called themselves a little or sometimes sensitive to noise. This is also mirrored by the answers to the question about regularly noise annoyance. 57 % find themselves annoyed by noise in their everyday life, 11 % sometimes, 32 % do not. More than half (60 %) of the noise annoyances are caused by traffic noise/vehicle noise. The second important noise source is domestic noise (18 %).

84 % of the TI state that they are using their car regularly.

About 80 % of the TI consider the evaluation task as not difficult or easy and about 20 % as difficult but feasible. Especially the evaluation of the stop_start situation and the comparison of the idle sound with other pass-by sounds (petrol_veh, diesel_veh) evoke such comments. Concerning the stop-start situation the TI has to summarize the perception of three or four different and partly very dynamic situations (approach/deceleration/idle/drive away). This seems to be a very demanding task. The same applies to the comparison of a very static sound, like the idle sound, with sounds, that are very dynamic, like pass-by sounds.

20 % of the TI encounter problems or irritation during the test. These irritations are mainly related to the software handling or the evaluation task. They could all be solved directly at their occurrence during the test. The other 80 % encounter no problems during the test. Everyone agrees that he would eventually participate again in such a test.

The short feedback about what influenced the evaluations gives indications on subjective evaluation parameters. The TI mostly describe acoustic phenomena which they perceive as annoying. Frequently named items are:

- diesel knocking,
- hissing,
- rumble,
- an even sound is better,
- whistling,
- unpleasant high frequencies,
- humming,
- diesel crackle.

Furthermore, the TI named properties that generally influenced their evaluations, e.g.:

- rolling noise / engine noise,
- loudness,
- acceleration.

These comments give valuable information about the sound properties that should be considered during the development of a quantitative description of the annoyance of pass-by sounds. Therefore, the qualitative comments have to be translated into acoustic parameters to allow statistical analyses.

The average standard deviation for the evaluation of a single sound is 1.15 categories. Interestingly, the standard deviation for the sound sets with unmodified sounds is only 1.03 categories, whereas for the sound sets concerning bonus / malus considerations it goes up to 1.30 categories.

The cluster analyses of the TI do not detect outliers. The Ward method shows almost always a typical grouping of two main clusters without imbalance. The cluster affiliation of the TI can also be found in the factor weightings of the PCA.

The comparison of the intro sound sets is done with the t-test method for independent samples. No significant differences between the sound sets can be found. This means that the TI show a high reliability over the different listening test versions. The same applies for the comparison of the two const50_equ sound sets.

Further the evaluations of the two test designs “category test with sorting” and “category test” are compared using the const50_equ sounds. Here also no significant differences are detected. Nevertheless, it appears that the TI use a slightly wider range of the scale if they are doing the category test with sorting.

3 SOUND ANALYSES

For the objective description of the annoyance of the sounds selected for the listening test acoustic parameters have to be found that mirror sound properties influencing the perception. The selection of these parameters bases on existing knowledge (found in literature and former research) as well as an additional search for appropriate descriptions of specific sound features, that are found important (by the TI or researchers).

Naturally, usually applied analyses like the SPL (sound pressure level) or loudness are considered.

SPL

The A-weighted SPL is the generally used and most common parameter for the evaluation of environmental noise. It is used for legal limits, in noise maps and international norms. The usage is often deduced from dosage-effect-relations describing the harmful effect of noise.

Therefore it is compulsory to include dB(A)-values in the analysis of the annoyance evaluations of the TI. The analysis will show if the A-weighted SPL is applicable for the description of annoyance.

In analogy to the L_{max} of the ISO 362 and the L_{den} of the noise maps the maximum and average SPL is selected.

Loudness

The Loudness is the psycho-acoustic equivalent to the A-weighted SPL. The parameter Loudness represents the perceived loudness of a sound. It is a subjective measure. The calculation method is described within the ISO 532.

There are a wide range of publications that prove the loudness one of the most important parameters regarding noise annoyance (see Fastl, Mellert, Berglund, etc.). Concerning vehicle noise it has shown that high correlations exist between annoyance evaluations and the specific loudness percentiles – particularly the 5% percentile (N5, see e.g. Patsouras).

The N5 Loudness percentile is selected for the analysis as well as the maximum value and the N1, N10 and N50 percentiles.

Diesel / Engine Noise

The most frequent answer to the question about sound features influencing the evaluation is “the sound of the engine”. Especially the typical sound of a diesel engine was described as very annoying.

A strong engine sound is characterized by its dominating engine orders in the low frequency range. The diesel sound has additionally a typical knocking pattern in the mid and high frequency range.

For the detection of these sound properties the analysis Relative Approach (RA) is used. The RA is capable of the detection of tonal components, frequency and time patterns within a sound. The RA was already successfully applied in former investigations about diesel knocking.

The RA simulates the adaptivity of the human hearing. The human hearing is very sensitive to patterns in the frequency and time domain. Monotonous signals cause a very fast adaptation, whereas permanently changing sounds and sounds with dominant patterns consistently attract attention (and can cause annoyance). The RA separates sound parts with and without pattern and thereby evaluates the contained patterns. An estimated signal – based on the previous values – is constantly compared with the actual signal. High differences are interpreted as dominant patterns. The capability of detecting diesel knocking is illustrated in Figure 5.

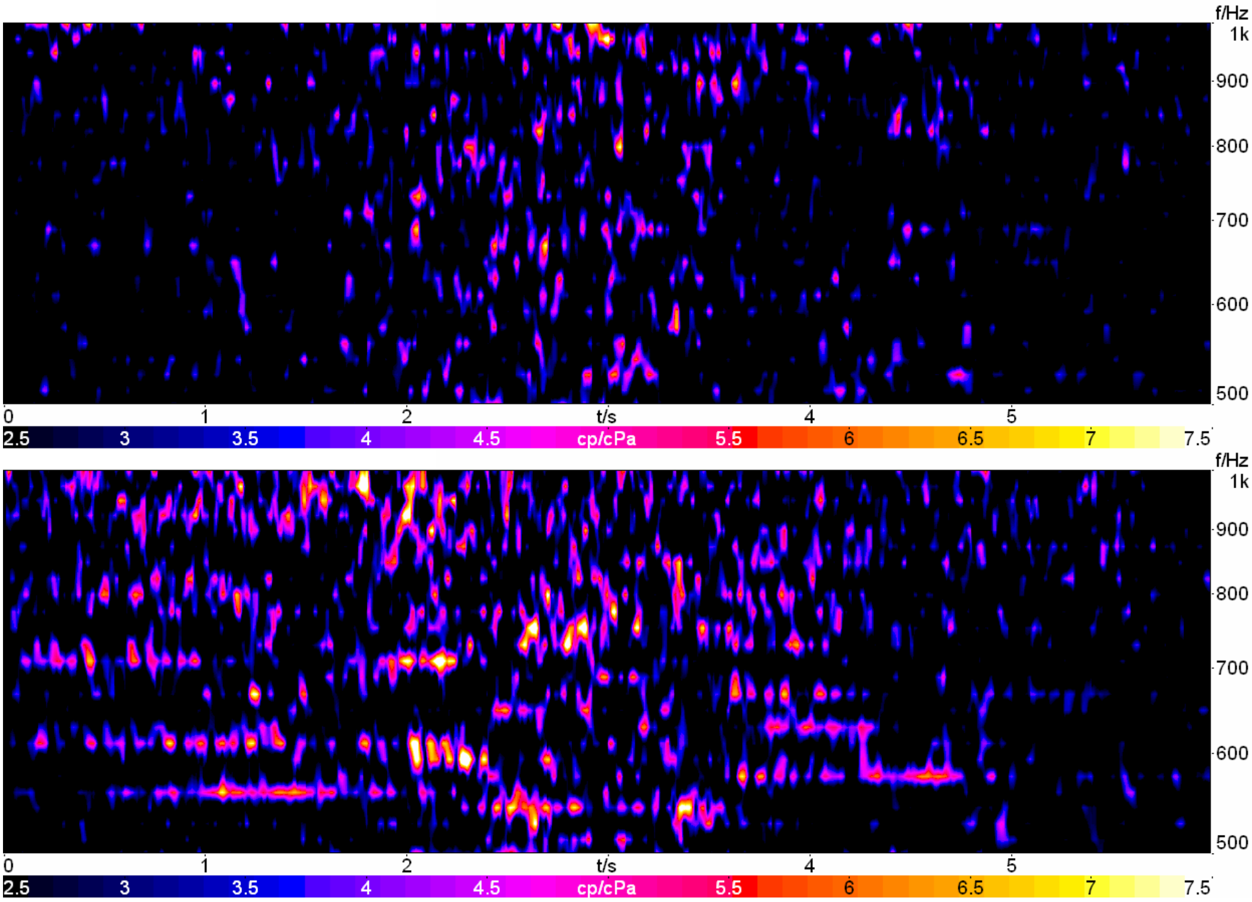


Figure 5: Relative Approach 3D. Example for a gasoline engine (top) and a diesel engine (bottom)

It is possible to apply the RA only to frequency patterns (RA(f)) or time patterns (RA(t)) or both (RA(f+t)). For the further analysis these three possibilities are selected. Additionally, the RA(f) analysis is combined with a low pass filter at 300 Hz for a better detection of the engine orders, and the RA(t) is combined with a band pass filter between 750 Hz and 5 kHz for a better detection of the diesel knocking pattern.

High Frequencies

Another typical sound feature that can cause annoyance by listeners is a high content of high frequencies in the frequency spectrum of a sound. Concerning pass-by sounds this can be caused by high levels of rolling noise. The consideration of this feature is also suggested by the TI comments. Besides the direct mentioning of rolling noise, terms like "hissing" indicate essential shares in the high frequency range.

The psycho-acoustic parameter for the assessment of this sound feature is the sharpness. Sharpness is a measure of the high frequency share of a sound. The greater the share of high frequencies the 'sharper' the sound is perceived. The calculation bases on the loudness calculation method described in ISO 532. The spectral loudness composition is then specifically weighted. Here the method of von Bismarck is applied. The sharpness unit is acum. Figure 6 depicts the spectral loudness composition for two vehicles with different sharpness.

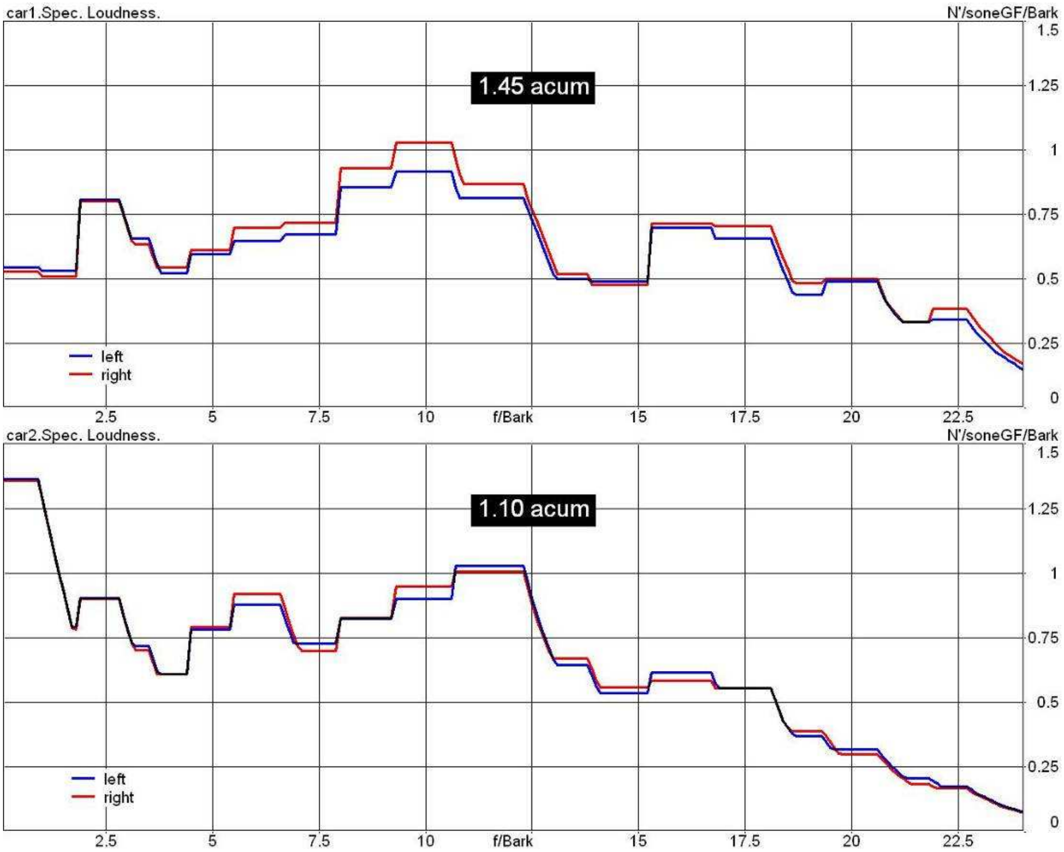


Figure 6: Specific Loudness. Example for a car with high content (top) and low content (bottom) of high frequencies and their respective sharpness value

In analogy to the loudness analysis the S1, S5, S10 and S50 percentiles are calculated for each sound file as well as the average sharpness.

Tonal Components

The occurrence of tonal components influences the perception. This relation is stated in literature (Zwicker, Aures. etc.), has influenced standardisation (ANSI S1.13, DIN 45681) and is also proved by the comments of the TI.

Besides the frequency and time patterns, the Relative Approach analysis assesses also the tonal components of a sound. But for the sole detection of tonal components the tonality analysis is considered too. Again, the four percentiles 1%, 5%, 10% and 50% are selected.

Low Frequencies

Dominant low frequencies emitted by the power train can cause high annoyance. They are described by the TI as "unpleasant humming noise".

Again, the Relative Approach is also considering frequency patterns in the low frequency range within its analysis. For an isolated assessment of the low frequency content a calculation method for a booming index was developed[5].

The principal idea of the booming index is the consideration of the loudness content below 250 Hz, inspired by the outcome of the EU project SVEN. Therefore, a parameter named "Booming1" is calculated as the absolute loudness below 250 Hz (unit: sone). Furthermore, a second parameter named "Booming2" relates this loudness content to the overall loudness of the sound; it describes the low-frequent share of the sound. Booming2 can be considered to be the opposite of the parameter of sharpness.

[5] The application of this index was preferred to an existing calculation method for a booming index (see Russell, Sung-Hwan) due to better handling and suitability.

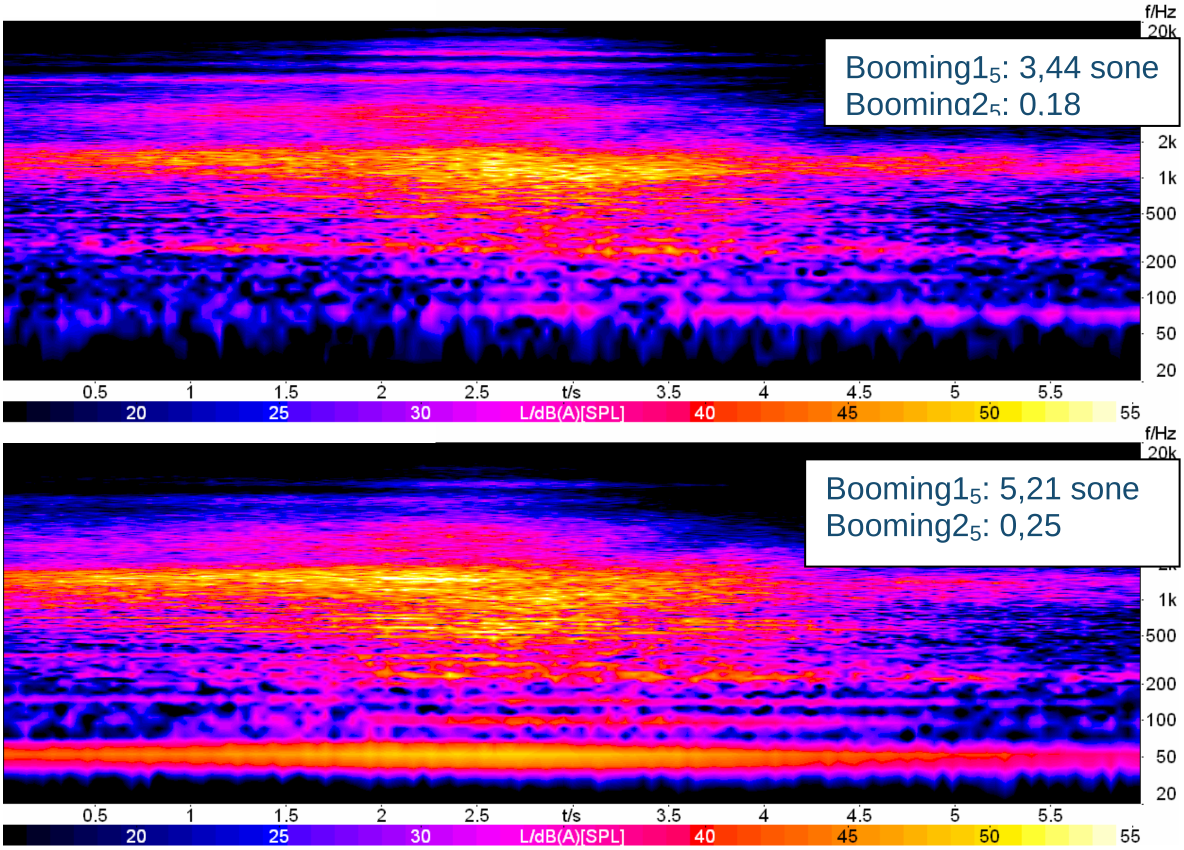


Figure 7: FFT vs. time. Example for a car with low content (top) and high content (bottom) of low frequencies and their respective booming indices

The 1%, 5%, 10% and 50% percentiles are calculated for each sound file as well as the average sharpness. Figure 7 depicts the FFT vs. time for two vehicles with different low frequency shares and their respective booming indices.

Loudness Variation

Some TI remarked that the loudness shifts within a sound influence their evaluation. Apparently, a sudden and high loudness increase can cause a high annoyance evaluation. Such a loudness increase can occur at an acceleration point. Comparing a constant pass-by at 30 km/h and one at 50 km/h the loudness slope is steeper for the latter one and so the annoyance can be higher[6].

Therefore, the loudness increase in the time domain is assessed by a custom developed parameter named “Δ-loudness”. It bases on the loudness vs. time analysis and evaluates the steepness of the positive slope of the loudness.

[6] The higher annoyance evaluation will be more likely due to the perceived higher speed and its related higher danger. But this interpretation can be translated into this acoustic parameter.

Ratio of High and Low Frequencies

The TI often mention the content of high or low frequencies in the sounds. Based on this, the idea is developed that the shares of the low and high frequencies should contribute to the sound at an adequate ratio, since if one of these is too dominating the sound will be rejected.

This ratio is calculated using the 5% percentiles of the parameters sharpness and Booming2. As a reference sound with an assumed optimal ratio of 9.2 serves pink noise. Other calculated values are referenced to this value. The assumption is that the bigger the difference the higher is the annoyance of the specific sound.

4 PRINCIPAL COMPONENT ANALYSIS

The principal component analysis (PCA) is applied to the evaluations for every sound set. It enables the determination of common factors that underlie the single evaluations.

4.1 THEORY

The evaluation of a sound set with *m* different sounds by *n* different TI produces a *n* x *m* evaluation matrix. The single evaluations of the TI will more or less differ from one another. It is now assumed that a few specific common evaluations factors are responsible for the evaluations and their different weighting for each TI causes the variations between the evaluations[7].

In the first step, the PCA tries to find a set of *m* evaluation values that has the maximum correlation with all the single evaluations of the *n* TI. This set of evaluation values owns also the maximum explanation for the variations[8] between the single evaluations of the *n* TI. It represents the first factor, which is characterized by its factor values (here the evaluation values for the sounds) and its factor loading representing the share of explained variation. The second factor is determined using the residual variations. This procedure is repeated until the determined factors together explain the total variation. This point is reached at latest with the factor number *n*.

The percentage of variation explanation and therefore the importance of a factor decreases with every iteration. There are different methods to determine the number of factors produced by a PCA relevant for the respective results. Here the Kaiser-Guttman-Criterion is chosen. This means, that only factors are considered that explain more than an evaluation of a single TI itself; factors with a lower explanation produce no further data reduction. This is mathematically expressed by the requirement of an eigenvalue higher than one for each factor to be considered relevant.

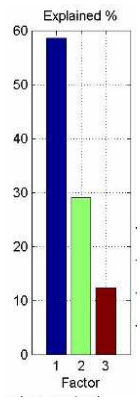
A typical result for a PCA will be the determination of two or three relevant factors that explain more than 80 % of the variations. So the initial *n* x *m* evaluation matrix is now represented by a *3* x *m* factor matrix. That explains also

[7] Example: A psychological test assesses the arithmetic capability as well as the spatial sense of a TI. The final result of each TI will base on these two factors and the variations between the results on the different individual capabilities regarding the two factors.

[8] Regarding the example, the total variation between the final results of the TI can be explained by their different individual capabilities. If the differences between the individual arithmetic capabilities are the same as the differences between the final results, this factor is explaining the total variation. Hence, the spatial sense has no influence on the differences of the final results; all TI perform equally concerning this factor. Typically, one factor is explaining only a certain fraction of the variations (this is a certain correlation between the differences) and the next factor explains a certain fraction of the residual variation and so on.

why the PCA is a method for dimensionality reduction. Figure 8 depicts the PCA principle for an example with three relevant factors.

TI	car1	car2	…
1	5	7	…
2	2	6	…
:	:	:	.:.
Ø	3,6	5,2	…



F	car1	car2	…
1	2	1	…
2	1	3	…
3	6	5	.:.
weight. Ø	3,6	5,2	…

Figure 8: PCA reduces the n x m evaluations matrix by determining the most relevant evaluation factors to a 3 x m factor matrix

To determine the meaning of the factors the respective factor values can be correlated with other values that stand for certain characteristics (here sound analyses) of the respective sounds. A high correlation between the factors values and a specific characteristic indicates that the factor is a good representation for that characteristic. This is the crucial point, where elements of the subjective perception are translated into physical sound analyses.

4.2 APPLICATION

The evaluation data is statistically analysed using MATLAB and its statistic toolbox. A graphic interface is adapted, so that – after the selection of a specific sound set – elements of the following groups can be user-defined selected or deselected (see Figure 9).

- TI,
- pass-by sounds,
- acoustic analyses.

The following statistical analyses include only the selected elements.

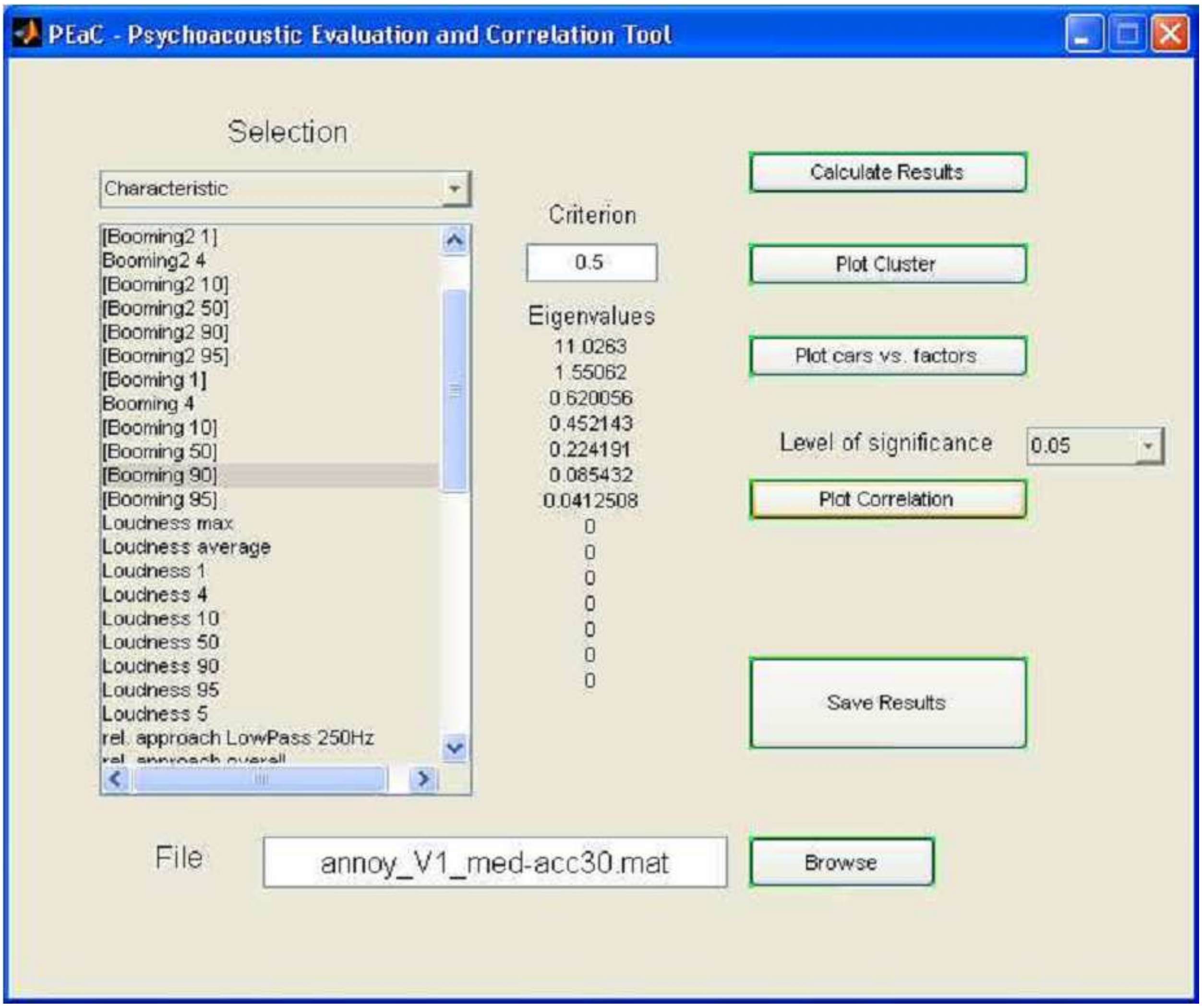


Figure 9: Interface for the statistical analysis of the evaluation data

Within this interface it is possible to define the eigenvalue criterion for the factor selection. As stated above, here a value of 1 is chosen according to the Kaiser-Guttmann-criterion.

Furthermore, cluster analyses for the TI or the sounds can be calculated and displayed in diagrams. Thereby, the variations between the evaluations of the TI and the sounds can be checked and outliers can be identified. The cluster analysis are performed according to the Ward method (tends to form evenly distributed clusters) and the average linkage method (tends to identify outliers better). Figure 10 depicts an example of the created diagrams. Every analysis produces a dendrogram as well as the curve of the increase of the square error sum with every clustering step.

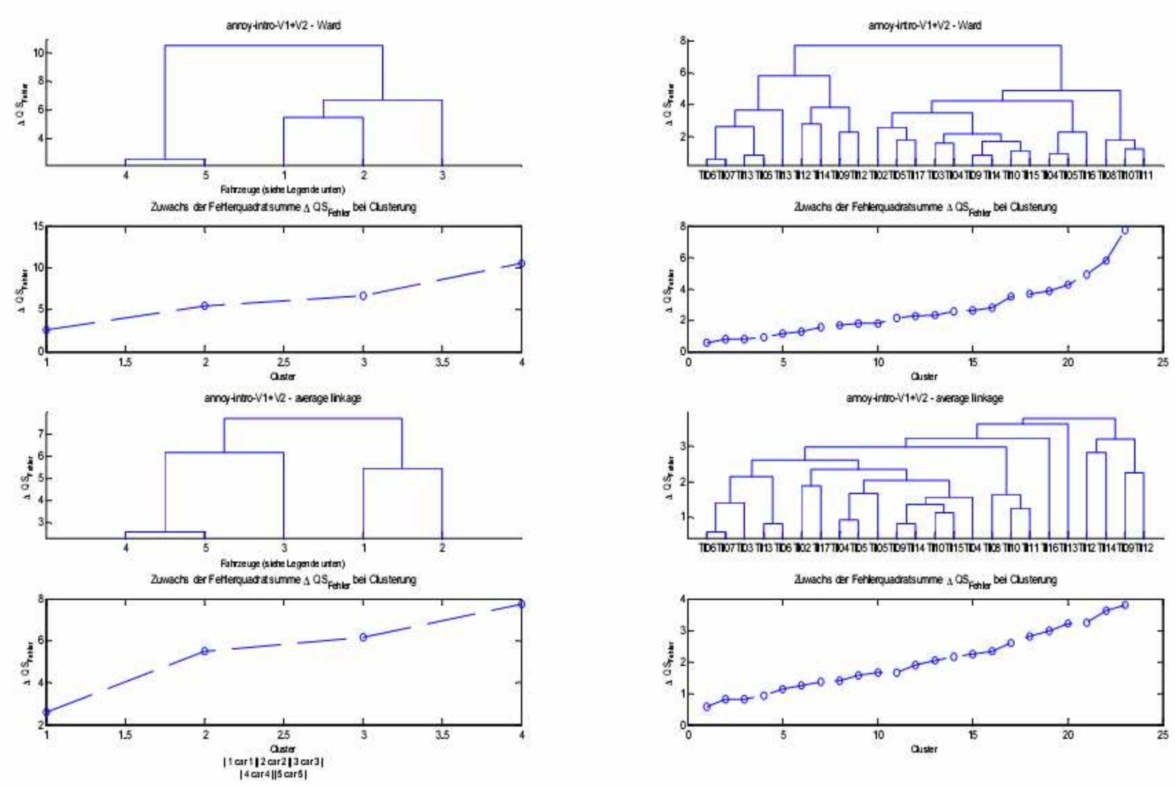


Figure 10: Cluster analyses of the sounds (left) and of the TI (right) using the Ward method (top) and the average linkage method (bottom)

It is possible to display the sounds using their new calculated factor values. Such a diagram showing graphically the distribution of the sounds over the factors can support the interpretation of the factors. Figure 11 depicts an example for such a diagram. Here the main factor (Factor 1) separates car 1and 2 from car 4 and 5. The comparison of these cars can hint on the meaning of Factor 1.

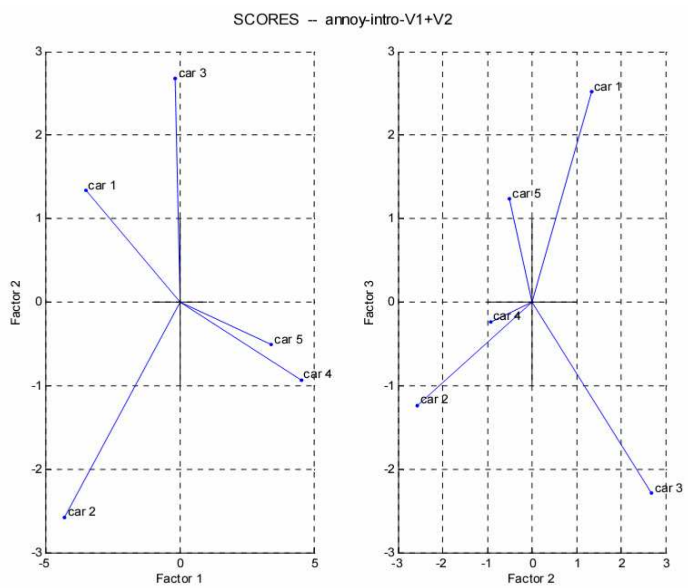


Figure 11: Diagram displaying the distribution of the sounds within the identified factors

Finally, linear correlations between the factors (i.e. factor values) and the selected sound analyses (i.e. calculated results for the respective sounds) can be calculated and again displayed in a diagram. The Pearson correlation coefficient is calculated for every factor complying with the eigenvalue criterion. The values of the correlation coefficient lie between -1 and 1. High absolute values indicate high correlation; the algebraic sign denotes the positive or negative linear relation. For the display the desired level of significance can be chosen. Figure 12 depicts an example for a correlation diagram basing on two relevant factors. The correlation for factor 1 are the blue columns, the ones for factor 2 are the red columns. Obviously, the analysis “S/B2” (ratio of high and low frequencies) gives a negative correlation, which is not sensible[9]. Factor 1 shows the best correlations for Boomimg1/2, Relative Approach and tonality. Factors2 seems to relate to loudness.

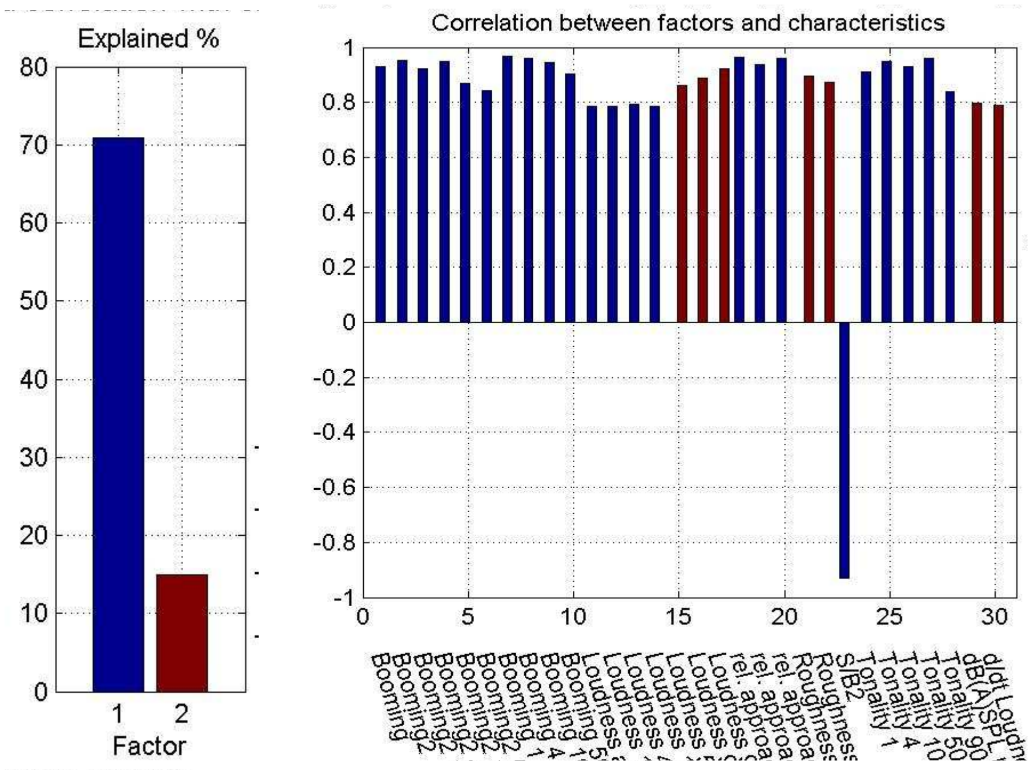


Figure 12: Example for a correlation diagram basing on two relevant factors

[9] This analysis never gave any important correlations and was rejected in the end.

5 EVALUATION INDEX EI

The results of the PCA and correlation calculations between factors and acoustic analyses describe the evaluation pattern of the TI and identify relevant parameters.

5.1 RESULTS OF THE PCA

The PCA of the 23 sound sets produce always one dominating factor with an explained variation between 60 % and 90 %. Looking at the diagrams displaying the distribution of the sound concerning this first factor it can be seen, that the factor clearly separates the diesel vehicles from the vehicles with otto engines. Figure 13 depicts the distribution of the sound for three sound sets. The vehicles with strong diesel engines (here: VW Caddy, Skoda Octavia) are on one end of the factor 1 axis and the low-key otto engines (here: MB E350, Opel Meriva) are on the other.

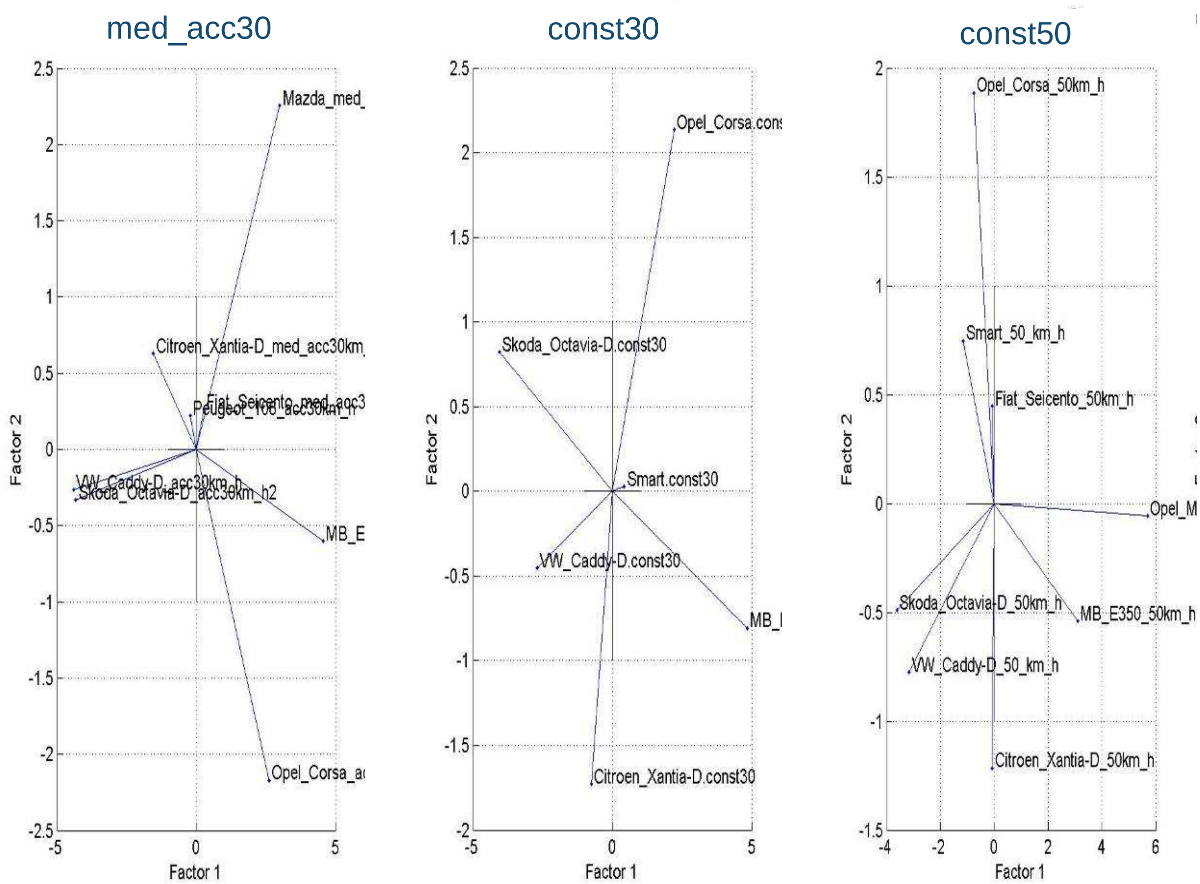


Figure 13: Distribution of the sounds over the first factor for the sound sets med_acc30, const30 and const50; the strong diesel engines (VW Caddy, Skoda Octavia) and the soft otto engines (MB E350, Opel Meriva) are clearly separated

The correlation calculations also prove this relation. The respective factor values correlate almost always with the RA(f) values at least with an correlation coefficient of 0.7 (see Figure 14 for two examples). The only exceptions are the sound sets idle_equ, med_acc30_equ and diesel_veh[10].

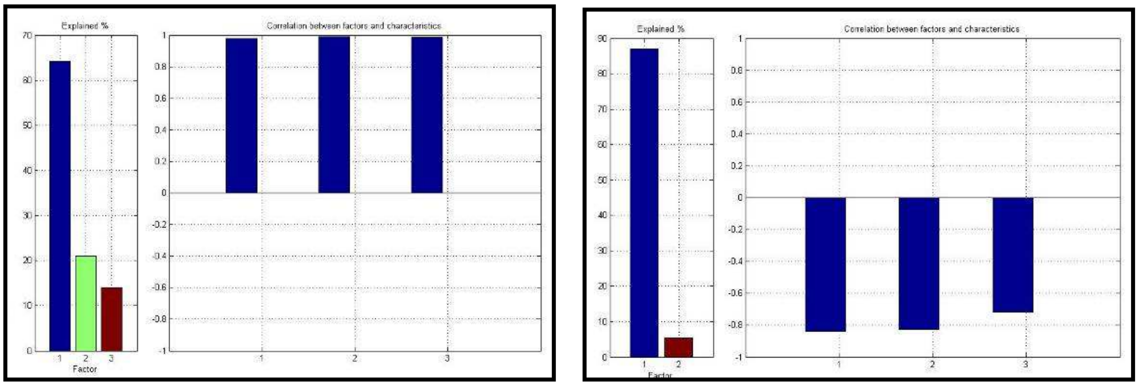


Figure 14: Two examples for the identified factors and their correlation with the RA(f), RA(f) with low pass filter and RA(f+t); left: intro (V1), right: const50_equ_cat (negative correlation due to orientation of the factor)

Therefore, it can be concluded that the evaluations are mainly influenced by the power train noise including diesel knocking and tonal components (mainly coming from the engine orders). The acoustic parameter RA(f) and RA(t) are describing these features and especially the RA(f) is considered to be a good representation of the first factor influencing the evaluations of the TI.

Further acoustic parameters that showed frequently high correlation with the first or second factor of the sound sets are the 5% percentile of the loudness N5 and the 5% percentile of Boomimg1. That the evaluations are influenced by the loudness of the sounds has been expected, as it is a common accepted relation. Additionally, the amount of the low frequency content seems to be a decisive parameter for the TI.

5.2 Creating the Evaluation Index

Starting from these results a **first approach** for the evaluation index is created. It should give a high explanation for all sound sets, because ideally it should describe the perception of a single pass-by independent of car type or driving situation. Since a high inter-correlation exists between the RA(f) and the $Booming1_5$, $Booming1_5$ is not included in the first approach for the evaluation index. So, the considered parameters are the RA(f) and the N5:

[10] Possible reasons for these outliers are discussed further below.

$$EI_{1st\ Approach} = \text{Relative Approach (f)} + 0.6 \cdot N_5$$

This equation weights the parameter at a ratio of 5 : 2 [11]. The weighting of the two parameters is based on the average weighting of the first and second factor calculated for every sound set, but is optimised for maximum correlation with the evaluations of the TI.

These correlations reach good and very good values between 0.71 and 0.99 for almost all sound sets.

The two exceptions idle_equ and diesel_veh can be explained with the different perception of an idle sound compared to a pass-by sound. Especially the idle sounds of strong diesel engines are much louder than these of moderate otto engines – that is why the index worked for the unmodified idle sounds. But at an unrealistic moderate sound level the repetitive pattern of the diesel knocking can be perceived as less annoying, since one can get accustomed to that pattern. For the diesel_veh set the TI often stated that it was difficult to compare the static idle sound to the dynamic pass-by sounds. The contexts for these sounds differ strongly. The idle sound indicates a vehicle that is not moving and will remain in front of the listener, whereas a pass-by sound belongs to vehicle that is moving – and maybe very fast – but passes by and disappears. Due to these differences in the evaluation context the results of the sound sets diesel_veh and consequently also otto_veh are discarded.

For a **refinement of the first approach** an additional test version V6 is designed. The main aim is the acquisition of evaluation data concerning the comparison of different driving situation (since the already evaluated sound sets cannot be used as stated above). Furthermore, it was tried to consider the whole range of sounds in one sound set to avoid scaling errors. Table 2 lists the configuration of the four sound sets for V6.

Table 2: Configuration of the sound sets for V6

V6	Set 1	intro_V6	training sequence
	Set 2	big_mix_diesel	11 sounds of different diesel vehicles at const30, const50, med_acc30 and roll50, pure category test
	Set 3	big_mix	30 sounds of different otto and diesel vehicles at const30, const50, med_acc30 and roll50, pure category test
	Set 4	big_mix_otto	19 sounds of different otto vehicles at const30, const50, med_acc30 and roll50, pure category test

[11] This ratio results if the factor 0.6 is normalised with the quotient of the average RA(f) value (32 cPa) and the average N_5 value (22 sone).

The analysis of the V6 evaluations together with the former results lead to the consideration of the 5 % percentile of the sharpness S5 and the RA(t) for the evaluation index. The sound features these two parameters are assigned to (e.g. high frequency tire noise or time patterns; see chapter 3) are named frequently by the TI and therefore should be integrated into the evaluation index. Furthermore, different sound sets show good correlation between S5 or RA(t) respectively and their second factor of the PCA. The improved equation is

$$EI = RA(f) + RA(t) + 0.4 \cdot N_5 + 10 \cdot S_5$$

This corresponds to a weighting of 1 : 0.25 : 0.35 : 0.45. The improvements concerning the correlation of evaluation and index values affect primarily sets without artificially modified sounds and without idle sounds, which are the most relevant sound sets for the EI. Table 3 lists the correlation coefficients for these sound sets (intro_V1-V4 combines the evaluations of the intro sound sets of V1 – V4).

Table 3: Correlation coefficient between evaluation values and EI values for relevant sound sets

Set	Evaluation ~ EI
Intro_V1-V4	0.99
const30	0.90
const50	0.92
med_acc30	0.91
idle	0.89
stop_start	0.81
intro_V6	0.97
big_mix_diesel	0.90
big_mix_otto	0.87
big_mix	0.93

It can be seen that the EI works very well for these sound sets. Nevertheless, the linear regression between evaluation and index shows that the sound sets idle and stop_start are relating very differently to the EI than the other sound sets. Therefore, sound sets containing idle sounds are excluded from the further considerations. The EI is developed for real pass-by sounds.

So far only single sound sets are compared to the EI values. The results for the big_mix sound sets of V6 indicate that the EI is also working for the evaluation of mixed driving situations, but for an **overall analysis** the evaluations of sound sets containing different driving situations are combined. By this, 72 single sound evaluations are the basis for the correlation of the EI with the evaluation scale. Further, the EI is adapted to the 9-point evaluation scale by linear regression.

Figure 15 depicts the mapping of the EI values to the evaluation values. The correlation coefficient is 0.91, the standard deviation 0.6. Only 8.5 % of the values differ more than one category from the actual evaluation values with a maximum deviation of 1.32.

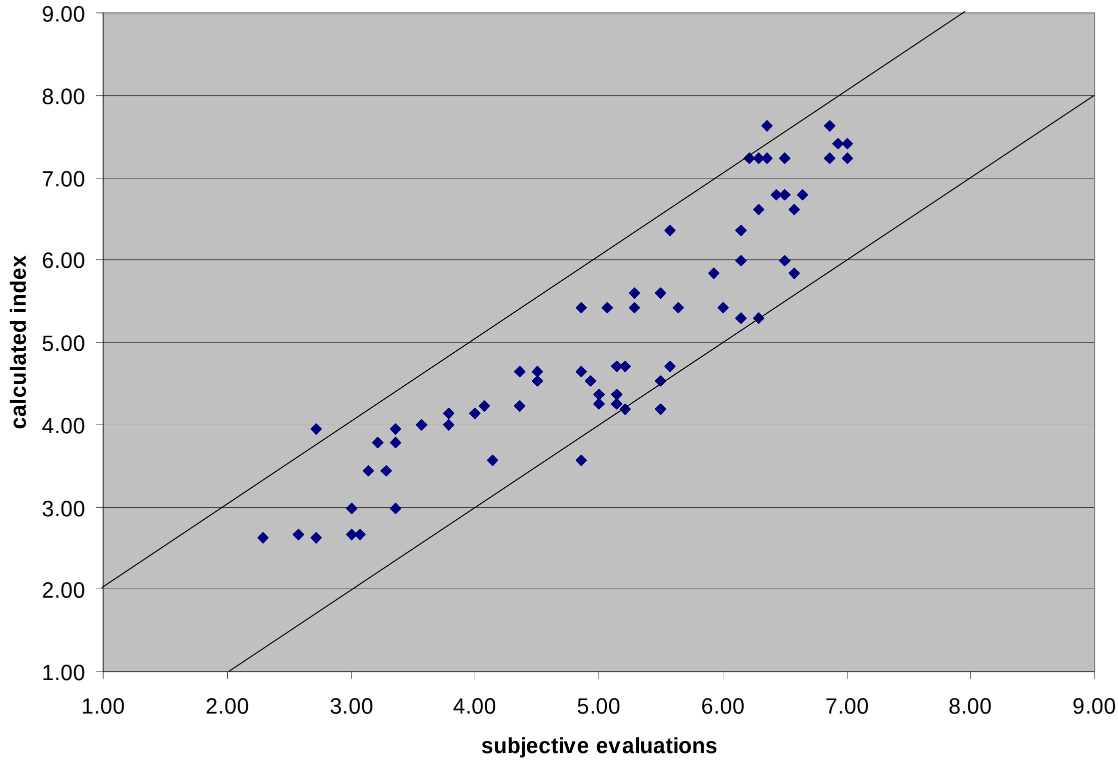


Figure 15: Mapping of the EI values to the evaluation values, diagonals indicating a ± 1 category hose

Since the currently used acoustic parameter for the evaluation of pass-by sounds is the SPL_{max} a **comparison between the SPL_{max} and the EI** is carried out.

Table 4 compares the correlation of the two measures with the evaluations for the relevant sound sets. The SPL_{max} clearly performs poorer than the EI, except for the idle and stop_start. But these two sound sets are generally excluded from the EI considerations. Figure 16 depicts the mapping of a SPL_{max} index[12] to the evaluation values. The overall correlation is 0.54, the standard deviation 2.1. 58 % of the values show a difference greater than one category from the actual

[12] The SPL_{max} values are adapted to the range of the annoyance ratings using linear regression.

evaluations. The maximum deviation is 4.81 categories; more than half of the evaluation scale. By these values a better performance of the EI then of the SPL_{max} is obviously proved.

Table 4: Comparison of correlations between evaluations and SPL_{max} and EI

Set	Evaluation ~ SPL_{max}	Evaluation ~ EI
Intro_V1-V4	0.69	0.99
const30	0.60	0.90
const50	0.66	0.92
med_acc30	0.70	0.91
idle	0.87	0.89
stop_start	0.88	0.81
intro_V6	0.54	0.97
big_mix_diesel	0.29	0.90
big_mix_otto	0.51	0.87
big_mix	0.53	0.93

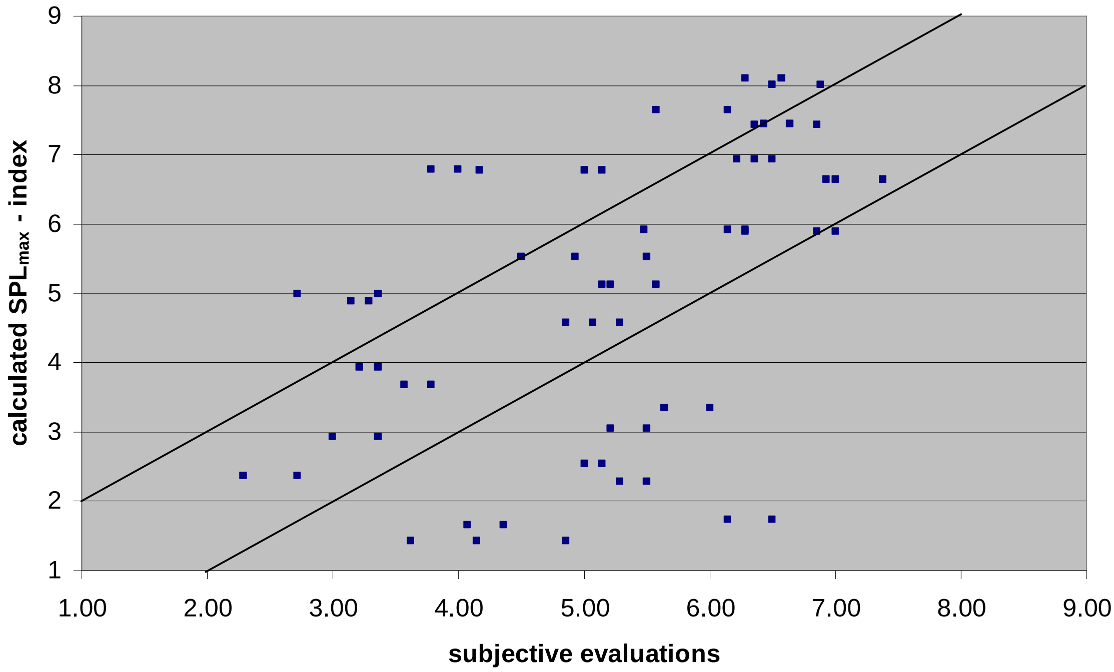


Figure 16: Mapping of the SPL_{max} values to the evaluation values, diagonals indicating a ± 1 category hose

The last step is the **adaptation of the EI to a common 10-point scale** (applied e.g. in the VDI 2563). The specific demands to this scale are

- 10 point scale from 1 (very annoying) to 10 (not at all annoying)
- no values below 1 or above 10 are possible

The reasoning for the last point is that if an unbearable sound is made e.g. louder it will not become “more unbearable” but remain unbearable. The same applies for not annoying sounds that are made quieter. So, the last point shall ensure that the EI analysis of sounds with extreme parameter values (e.g. very loud or very quiet sounds) does not produce values outside the specified range. This risk is given by applying a simple linear relation.

For the construction of this scale an adaptation function basing on an exponential function with a cubic argument is applied upon the current EI formula. Figure 17 depicts the course of the transformation function between the two scales. The actual evaluation values between 1 and 9 are mapped to the linear range of this function.

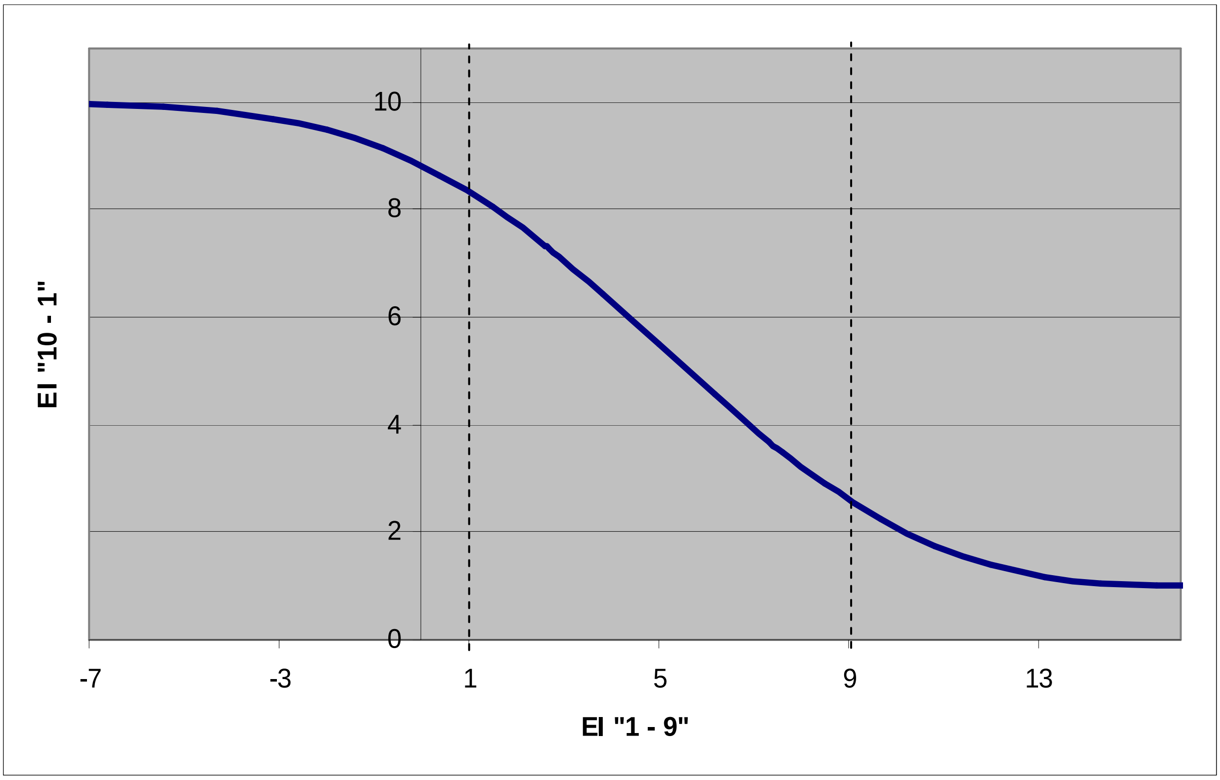


Figure 17: Transformation of the EI scale from “1 – 9” evaluations to “10 – 1” scale

Very annoying sounds that would create EI values higher than 9 cannot produce values lower than 1 on the new scale, and the values of very quiet sounds go asymptotically against 10. The transformation has a negligible effect on the quality of the correlation.

The final equation for the EI on a 10 to 1 scale is

$$EI = -\left(9 \cdot 2^{\left(\left(\frac{RA(f)+RA(t)+0.4\cdot N_5+10\cdot S_5}{59.88}-2.12\right)^3\right)}+1\right)+11$$

with

$$EI = 1 \quad \text{when} \quad \frac{RA(f)+RA(t)+0.4\cdot N_5+10\cdot S_5}{59.88}-2.12 > 0$$

This equation is implemented into the TrafficNoiseSynthesizer which is available to the partners. It is suitable for real pass-by sounds that produce EI values 3.5 and 7.3 (corresponds to the maximum and minimum evaluation values). Planned investigation within QCITY will lead to further refinements, e.g. for filtered sounds or traffic flow sounds.

For **verification** purposes a further test version V7 was compiled including one sound set with new pass-by sounds (ver_new) and one sound set combining new and old sounds (ver_old_new).

The sound set ver_new serves purely to test the performance of the EI when confronted with new pass-by sounds. The gained correlation was 0.87, which proofs the EI to be valid also for sounds not analysed so far. Since very loud truck sounds – reaching a 1.18 on the EI scale – are included in ver_new, the asymptotic scale design is approved too.

The sound set ver_old_new is intended to analyse the influence of new sounds on the range of the subjective ratings. As stated above the new sounds include very annoying truck sounds. As expected, this leads to shifting of the not so annoying sounds towards the lower end of the evaluation scale. The relations between the single sound ratings are not influenced by this shifting, since the correlation still remains on a very high level (0.96).

5.3 BONUS / MALUS

Several listening tests with modified dB(A)-values are conducted for the determination of an dB(A)-equivalent for the increased annoyance of certain vehicles groups like diesel or heavy vehicles. Unfortunately, the analysis of these listening tests turns out to be very problematic.

On one hand, the deviations between the evaluations of the TI are rather high with an average of 1.3 categories. On the other hand, the ratings of vehicles within one vehicle group show also a wide spread. This applies naturally also for the EI values of the vehicles.

Nevertheless, some preliminary results can be obtained. It seems that a dB(A)-equivalent depends on the respective driving situation. For instance, the differences between vehicles with loud diesel engines and the ones with otto engines emerge more clearly with rising speed. The estimated bonus / malus values for these two vehicle groups are about 4 dB at const30 and 5 dB at const50.

But, for an averaging of the differences between two vehicles groups it would be necessary to identify the dB(A)-equivalent for each possible sound pair out of these two groups. Due to the high deviations mentioned above this procedure can give inaccurate results.

It is much more reasonable to perform further investigations concerning the bonus / malus with traffic flow noise, where specific combinations of vehicles within one group or out of two groups can be realized. The implementation of such a feature into the TrafficNoiseSynthesizer software will be made within WP5.12. So, the investigation will be continued within WP5.12. There, the listening test to be conducted will serve also as a first quality and acceptance test for the synthesized traffic scenarios.

Together with the EI – which will also be subject to refinement within WP5.12 – it will be possible to define rules for the application of the bonus / malus. The simplest solution is the principle application for e.g. diesel vehicles. But if the assumption is true, that the bonus / malus value depends on factors like driving situation or general annoyance level, other application methods have to be found. One possibility for the combination of the bonus / malus and the EI is the definition of a threshold value derived from the EI or its components. Alternatively, the bonus / malus could be applied progressively if it is possible to define an EI-dB(A)-relation or something similar for these cases.

6 CONCLUSION AND OUTLOOK

The pass-by sounds compiled during the first twelve months of WP2.1 (see D2.1 and D2.2) were analysed regarding their perception and psychoacoustic characteristics. The two aims were to find a quantitative description for their subjective annoyance effect and a dB-equivalent for the different annoyance effect of different vehicle groups (bonus / malus), like vehicle with diesel and otto engines.

On one hand, extensive listening tests were carried out for the psychoacoustic evaluation. Thereby, traffic noise is evaluated by test individuals (TI) regarding its annoyance and not only in terms of the SPL / dB(A). On the other hand, different psychoacoustic parameters were calculated for these sounds. The selection of the psychoacoustic parameters was carried out with respect to psychoacoustic measures commonly used when analysing the perception of vehicle noise as well as respect to the comments of the TI and own considerations about pass-by sounds of single vehicles.

The principal component analysis (PCA) was applied to the TI ratings of the listening tests. Hereby, similarities between the single evaluations of the TI could be discovered and common factors influencing the evaluations could be determined. Comparison and correlation of these factors with the calculated psychoacoustic parameters identified parameters that can represent the evaluation factors.

The most important factor was highly correlated with the Relative Approach analysis (RA). The RA simulates the adaptivity of the human hearing and is able to detect time and/or frequency patterns within the sound the human hearing is very sensitive to. Here it identifies the noise of diesel engine or strong engine noise in general. This fits also the comments of the TI, which described the characteristic diesel knocking or typical diesel engine noise as very decisive. The second important parameter was the 5 % percentile of the loudness N_5. This was not surprising, since in literature it is often related to annoyance

After further considerations and listening tests the list of relevant parameters was extended by the 5 % percentile of the sharpness (relating to TI comments like "high frequency tire noise). The gained equation for the evaluation index EI representing the evaluation ratings of the TI was fitted to a 1 (not at all annoying) to 10 (very annoying) scale:

$$EI = -\left(9 \cdot 2^{\left(\left(\frac{RA(f) + RA(t) + 0.4 \cdot N_5 + 10 \cdot S_5}{59.88} - 2.12\right)^3\right)} + 1\right) + 11$$

with

$$EI = 1 \quad \text{when} \quad \frac{RA(f) + RA(t) + 0.4 \cdot N_5 + 10 \cdot S_5}{59.88} - 2.12 > 0$$

This equation was also proved in validation test with new pass-by sounds.

In WP5.12 this EI will be enhanced and adapted for filtered pass-by sounds (e.g. representing pass-by noise in flats or behind screenings) as well as traffic flow noise.

The bonus / malus investigation gave only preliminary results. The estimation of a dB-malus between 4 dB and 5 dB (depending on the speed) for diesel vehicles have to be further investigated in WP5.12 when it is possible to evaluate traffic flow noise.

The bonus / malus results gained within WP5.12 can be combined with the EI. Rules for the application of the bonus / malus will be defined also in relation to the EI or its components.