A New Approach for Developing Vehicle Target Sounds

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Today, vehicle interior noise is an important customer satisfaction criterion. Acoustical engineers need to identify and eliminate disturbing noise components to maintain a competitive advantage. In fact, vehicle sound must be deliberately designed. This means that to create driving satisfaction, certain noise aspects have to be emphasized and others reduced. Vehicle engineering needs to be extended to design-engineering and the exploration of preferred sounds. Furthermore, simulation of new engine sounds or even the sound of the entire vehicle at early stages in the development phase has become increasingly important. For example, different engine mounts can be virtually built in and their effects on interior sound can be examined without expensive iteration loops using physical prototypes. This article presents new tools for sound design and target sound development. In particluar, we introduce a new subject-centered method – Explorative Vehicle Evaluation (EVE), for determining target sounds.

Vehicle variety and customer expectations continue to grow. Automakers try to meet increasing quality and comfort requirements via increased R&D. Emotional criteria have replaced previously objective, pragmatic demands. Meeting customer needs – comfort, driving pleasure, design – have become as important as functional criteria. The automotive industry recognized this shift in demand and now advertises its products with emotion-related slogans and motifs, including new catchwords such as passion, thrill, excitment and desire.

The vehicle sound experience is an increasingly important factor that significantly influences driver satisfaction. This parameter is addressed by the NVH section of car manufacturers. For more than 20 years, NVH quality has been a vital task for acoustical engineers. But until now, they haven't developed target sounds, but rather work only on 'symptoms.' The process of troubleshooting and eliminating disturbing noise components is indispensable. However, does the avoidance of unwanted noise phenomena mean that the resulting sound is adequate or optimal for a respective vehicle?

Target Sound

To attain a customer-oriented, client-specific target sound, potential clients and their specific demands must be considered and integrated into the development process. Conventional marketing research tools collect this kind of information. But the knowledge gained is often insufficient to develop specific vehicle sounds. These can include a well-balanced configuration of engine orders, characteristic resonances, adequate turn signal noise, etc. Specific data on noise properties must be determined with the help of listening tests that consider vehicle class, image, interior and exterior design, target customers, performance and so on.

Driving simulators can be used to determine the necessary sound properties of a new vehicle. This allows new vehicles to be virtually experienced before the first costly prototypes are actually built. Incorporating target sound specifications into the development process leads to improved product quality at early stages and can result in a significant enhancement of product acceptance by customers. This can also lead to increased brand loyalty when customers are shopping for a new vehicle.[1]

How to Get There

Listening tests of various sound designs are carried out to collect data about subjective evaluations of predefined stimuli. For reproducibility, these tests are often standardized and conducted in a 'controlled' environment. Standardized test conditions should allow for provable statistical correlation between subjective ratings and objective parameters. At times, however, a stimuli representation is taken out of context and a response limitation (pressing complex sensations into given scales) leads to biased results that often cannot be generalized and confirmed under actual operating conditions. Other test conditions can moderate a subject's perception and evaluation of stimuli such as context, ambiance, interactivity and occurrence of several sensory inputs at the same time (combined stimuli).

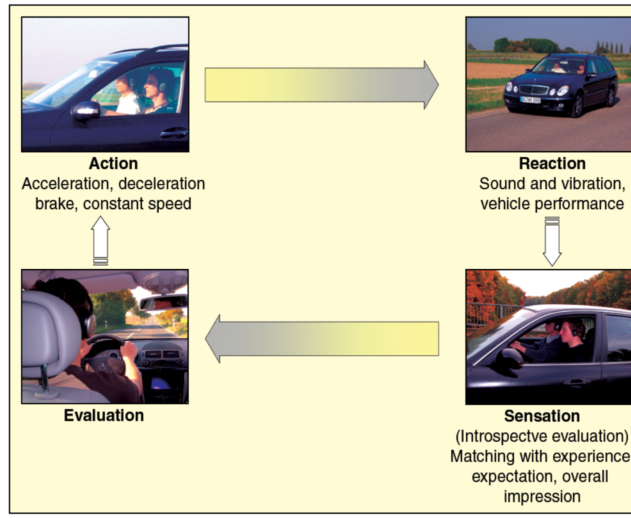

Figure 1. Evaluation process in everyday life.

Evaluation of vehicle noise depends on several features besides the noise itself. Vehicle sound quality is based on combined vibro-acoustic exposure. If these additional factors are neglected, test results may be biased. For example, several studies have revealed that vibration exposures considerably influence perceived sound quality.[2] Distracting vibrations will subliminally influence evaluations and lead to inaccurate sound quality assessments. Furthermore, context, ambiance and interactivity are also meaningful factors in which sound evaluations are usually embedded.

Developing and applying new types of listening tests regarding reality-relevant aspects of the driving experience seems imperative. The Explorative Vehicle Evaluation method (EVE) has been developed and applied in connection with target sound development. The method is based on laboratory-oriented exploration of Associative Imagination on Sound Perception (AISP)[3] that has been applied in a EU-research project called OBELICS.[4] The new method is designed to be conducted in test surroundings close to reality and to include spontaneous associations, feelings and noise evaluations from the test participants.

The EVE method, as shown in Figure 1, considers the environment where vehicle sound evaluations are made, the interactivity that occurs between the driver and the vehicle in common driving situations, the spontaneity of evaluations in real driving situations and the experiences of the test individuals. An advantage of this method is that the test participants create their own stimuli, act on their own initiative to evaluate sounds heard, and can explain their feelings and judgments in an open and free way, not confined to forced answers that are limited by predefined quantities and

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Figure 2. Different test scenarios, left to right – laboratory setup, stationary driving simulator, mobile driving simulator.

scales.

The EVE method considers only perceptually relevant noise events based on verbalized associations and sensations. Evaluated events are identified and further analyzed in detail with respect to an optimal or preferred vehicle vibro-acoustic setting. A summary of essential EVE features is listed in Table 1.

Mobile Sound Simulation System

People don't evaluate stimuli based on a single dimension. In fact, it is more a question of interaction between the various levels of perception. The EVE sound simulation system allows examination of different sound stimuli. Evaluated sound events are recorded in an aurally accurate manner. By means of complex synthesis algorithms, the sound simulation system provides vehicle interior noise stimuli that correspond to actual driving conditions. Based on measured data, the sound simulation system can reproduce any vehicle sound in a given test vehicle.

Engine sound, tire and wind noise – both dependent on speed, load and rpm – are provided in realtime to the driver's ears. The vehicle sound playback is adjusted to monitored control parameters. The sound simulation system utilizes BTPA and BTPS (Binaural Transfer Path Analysis and Synthesis) techniques to allow simulation of specific sound sources and transfer paths. These can be separately examined with respect to their contribution to overall noise evaluation.[5]

Test participants often forget the fact that they wear headphones because of the authentic driving conditions and appropriate noise playback. Their comments and evaluations are considered to be highly reliable. The separation of different "sound sources" allows detailed consideration of specific contributions to perceived sound quality.

The major difference between a sound simulation system installed in a real vehicle and well-known laboratory sound design tools is that all sound perception effects occur within a very realistic setting – the drivable 'virtual' vehicle.[6] The three commonly used test settings are illustrated in Figure 2.

A mobile sound simulation system provides a realistic noise and vibration environment when using a real vehicle. However, the vibrational features are fixed and cannot be changed to study the influence of various parameters on the evaluations. In contrast, a stationary sound simulation system allows control of the vibrational stimulus, but the authenticity of the driving situation is reduced. A realistic test environment is required to determine a vehicle's target sound and applying the mobile driving simulator is imperative.[7]

Explorative Vehicle Evaluation

Test Design. After passing a suitability test with respect to hearing ability and target-customer specifics, the test participant obtains detailed instructions for the test and gets time to become familiar with the test vehicle (adjusting the steering wheel, seat position, mirrors, etc.). The test participants are asked to drive in their accustomed manner.

During the drive, a test person reports all present associations, feelings, emotions, impressions and ideas concerning the driving situation, the sound of the vehicle or the vehicle itself. Therefore, the evaluations are verbal reactions according to self-administered stimuli. Verbal evaluations, their respective noise and vibrations and specific operating data (speed, rpm) are recorded and constitute the data pool for analysis (see Table 2). A pre-trigger is applied to make it possible to record complete statements and corresponding data about the driving situations to which the comments refer. Moreover, the instructor notes assumed important observations about certain events, such as gestures, emotions or behavior of the driver. These data can also be used in the analyses.

To verify comments and collect further significant data for creating a target sound, evaluations and corresponding noise events are played back and discussed in a follow-up interview. The interview is conducted in the vehicle to aid memory. The different remarks are presented, and the instructor requests the test participant to describe and explain his or her comments in detail. During this detailed inquiry, the instructor can explore the emotional, social, psychological or contextual parameters of the sound evaluation. The background for the embedded decision to accept or reject a certain sound in a specific driving situation can also be evaluated. This part of the interview is known as "communicative validity"

Table 1. EVE features and advantages.

EVE Feature	Means	Advantage
Test in most authentic surroundings	Sound simulation system turns typical vehicle into a NVH driving simulator	Target sound development considers impact of vehicle's specific ambiance on sound perception (with its appearance, haptics, ergonomics, etc)
Reflection of interactivity processes	Sound simulation system simulates vehicle noise independent of test participant's actions	Evaluation of only self-stimulated stimuli
Test participants explain their evaluations with their own vocabulary	Qualitative analysis method allows systematic analysis of comments and evaluations	Increased explanatory power of test results because of open test design (no restricting hypotheses and predefined scales)
Context sensitivity	Test participants drive test vehicle according to their accustomed manner in a most authentic situation	Test persons reliably evaluate familiar driving conditions close to reality
Examination of only perceptually-relevant noise phenomena	Test participants decide on time and number of given evaluations; no forced answers	Target-oriented acoustical analysis
External validity	Realistic test situation and familiar form of verbalization lead to most reliable data	Specific test design allows generalization of test results (with adequate samples)
Deepen of relevant phenomena	Following semi-standardized interview allows detailed examination of evaluations	The process of communicative validity enhances reliability of results

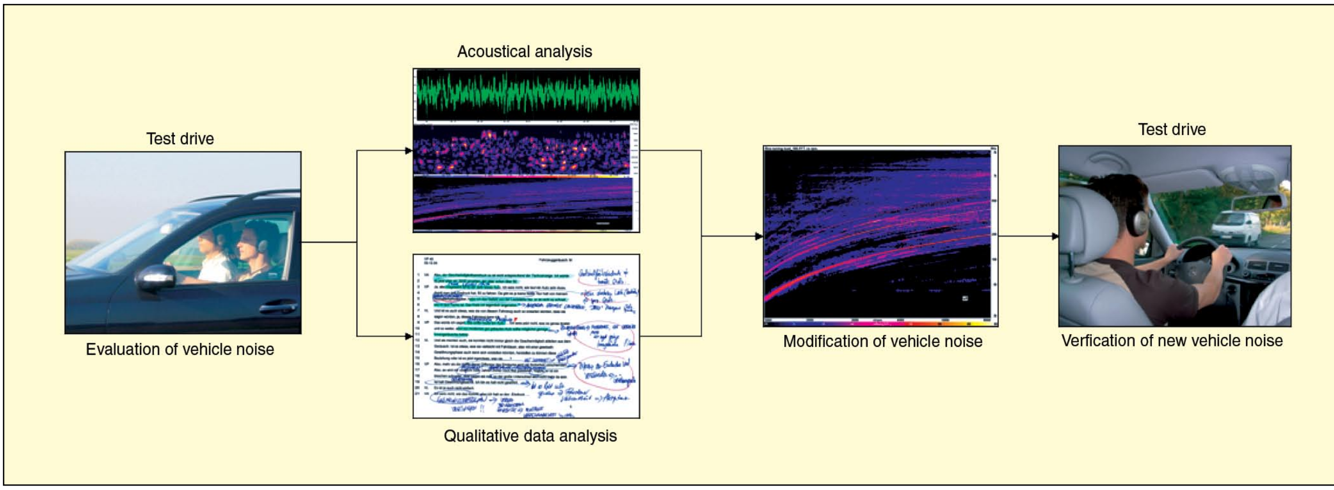


Figure 3. Important steps in the Explorative Vehicle Evaluation process.

in qualitative research.

Process of Target Sound Development. The analysis of comments with a qualitative analysis technique (grounded theory) gives insight into the perception and evaluation of vehicle sounds. Detected phenomena are coded with general notations during the analysis stage. The purpose of the analysis is to group similar events, sensations, or reactions under a common heading or classification and to discover intersubjective evaluation patterns. But the analyst does not interpret the material. Instead, the analyst only enhances the level of abstraction to improve generalization. This means conceptualization instead of description.[8] Thus, it is not only an exploratory tool for a quantitative study, but also permits development of the theory and identification of relevant moderators for perception.[9]

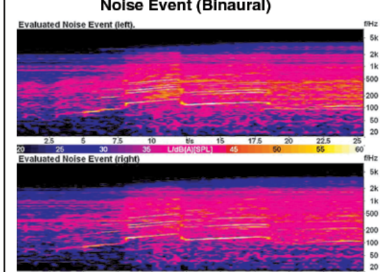
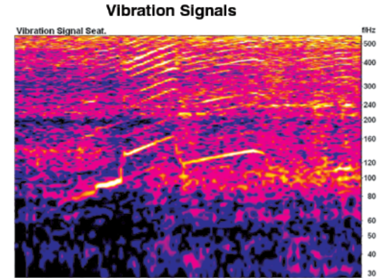
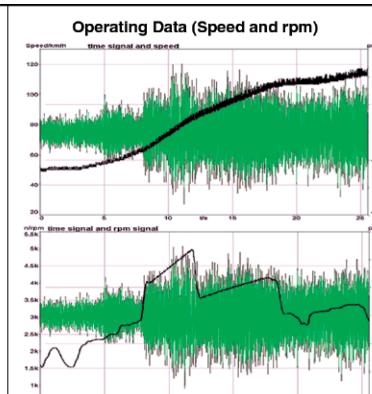
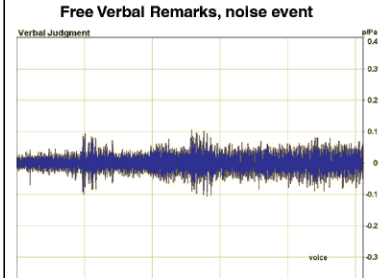
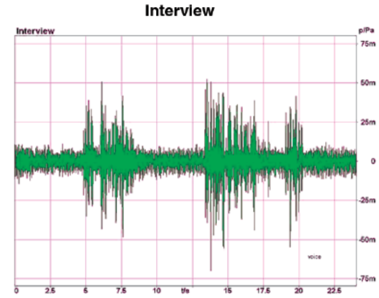
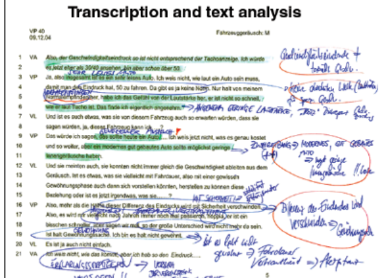
Based on the results, information concerning the character and features of a preferred vehicle sound is derived. On the basis of the first EVE tests, a vehicle sound is developed considering the different remarks and comments, customer preferences, acoustical analyses and generated theory. For example, the theory provides information about general expectations, preferred overall character of the vehicle noise or certain acoustical properties that will positively contribute to an accepted sound. The conclusions result in a modified vehicle sound, which is subsequently implemented in the mobile sound simulation system. This procedure is schematically depicted in Figure 3.

This new vehicle sound has to be evaluated again with the help of further EVE tests until the developed sound is verified and affirmed by test participants. Applicability of the developed vehicle sound with regard to the vehicle and target group can only be guaranteed by this procedure. This implies that the created vehicle sound is not objectionable and leads to a high level of contentment and driving pleasure.

The iterative, circular process of developing the target sound allows an unerring determination of a vehicle's target sound and an almost unlimited fine-tuning depending on target specifications. The number of iterative loops is not fixed and depends on the step-wise progress of target sound development and an "exit condition." This process is shown in Figure 4.

The mobile sound simulation system offers the opportunity to modify a vehicle sound on line. An extension of the EVE method is conceivable. The co-driver (investigator) can modify the vehicle sound on line (see Figure 5), while the test participant is driving to examine the influence of specific acoustical parameters on the evaluations. The investigator can interactively change certain

Table 2. Typical Explorative Vehicle Evaluation (EVE) data base.

	Noise Event (Binaural)	**Vibration Signals**	**Operating Data (Speed and rpm)**
Acoustical Data			
	Free Verbal Remarks, noise event	**Interview**	**Transcription and text analysis**
Evaluation Data			

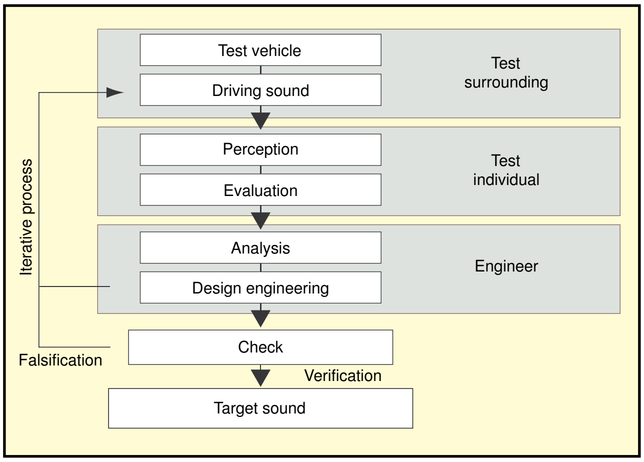


Figure 4. Target sound development levels.

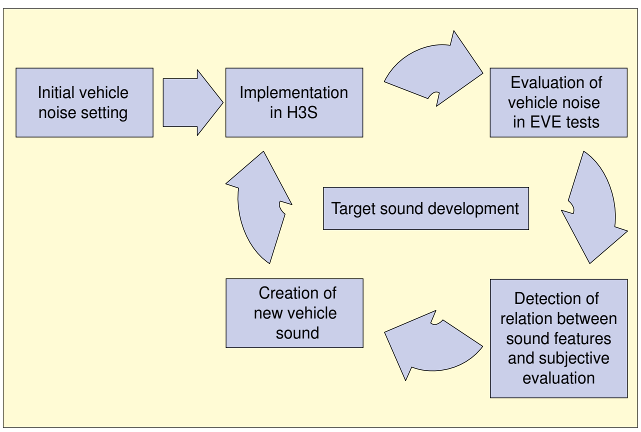


Figure 5. Process of target sound development.

properties of the vehicle sound (by means of different filter techniques such as rpm-dependent filters) to study the impact of these changes on perceived sound quality.

Modification of a vehicle's 'soundscape' during the test drive for an interactive sound design should not be carried out with naïve test participants. The reduced reality of the driving situation will influence evaluation behavior.

Conclusions

Sound and vibration parameters must not only be considered as disturbing elements regarding NVH comfort, they can also be used to develop an acoustical and vibrational environment that influences positive customer satisfaction. The creation of sounds that give the impression of high product quality helps manufacturers stand out against competitors and meet increased requirements. Sound quality considerations and target sound development require multi-dimensional approaches integrating new and interdisciplinary methods. A sound simulation system installed in a drivable vehicle allows target sounds to be determined accurately. The advantages of the EVE approach are:

Figure 6. Investigator with simulation control unit.

- Development of more marketable products.
- Fast implementation and efficient testing of new sounds with respect to a product's target sound.
- Target sound development based on the most convincing evaluation data.
- Easy verification of new products with respect to market readiness, even for nonacoustic aspects.

The design of EVE is flexible. The procedure of free evaluations of vehicle noise while a test person is driving can be extended to benchmarking tests and interactive sound design. The implications of such extensions have to be studied carefully to avoid bias effects and test environment artifacts.

Furthermore, the sample has to be carefully selected with respect to intended target group to guarantee the external validity and generalization of test results. The mobile driving simulator and EVE reliably guarantees determination of target sounds with a high degree of validity due to reality of the test environment.

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