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Development of a method and a test rig to evaluate the outer handle snap back sound of passenger cars

Master's thesis in Sound and Vibration

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MASTER'S THESIS BOMX02-16-66

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Reproservice / Department of Civil and Environmental Engineering

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Abstract

For a premium car the sound of each component is important for the overall impression of the car. Among others like for example seat adjusters and the door closing, the sound of the outer door handle snap back is one of the first the customer experiences in a dealership. To be able to evaluate this sound in an early stage of development, a test rig and a method is developed in this thesis. Furthermore requirements in terms of objective measures are determined which correlate to the subjective impression of a customer.

This study is focused on one particular handle design which is modified in different ways in order to obtain different snap back sounds. All possible combinations of these modifications are recorded and the acceleration is measured on various points. This is done on three different measurement setups each. One setup is the handle mounted on the complete vehicle, second the handle mounted on a metal sheet, and third only the handle itself.

The recordings of the complete vehicle measurement are used to perform a listening test to find out what high quality of a door handle snap back means for a potential customer. The result of this subjective investigation is compared to the analysis of the objective microphone signal and then step by step transferred to the results of the acceleration measurements of the complete vehicle setup, the metal sheet setup and the single handle setup.

Finally as the outcome of this study a correlation between the subjective perception and the objective measurement of the door handle snap back sound could be found.

It is shown that it is possible to use a test rig with a very reduced design. Moreover a suggestion for a requirement curve in terms of acceleration level on the handle is given.

Contents

Acknowledgements

First of all I want to thank Wolfgang Kropp, my supervisor at Chalmers, and Patrik Johansson, my supervisor at Volvo Cars, for the great support during the whole project.

Furthermore thanks to everyone who participated in the listening test. You made a very important contribution to my investigation. Thanks also to Stefan from HEAD acoustics for the help with the software and of course to all my colleagues at Volvo Cars for the great integration.

Last but not least a special thanks to Ola and Stephan, who pushed me and distracted me always at the right time!

1. Introduction

The door opening process is the first physical contact of a customer to a car. It takes place even before the door closing, where there is already a lot of research about. The first impression of a new car is the optical, followed by the tactile and the acoustical. If it feels and sounds cheap, it does not fit to the overall high-quality impression of a premium car.

The handle is the first item of a car that is touched and used by a customer and after the handle-pulling noise and the door-opening sound, the handle-snap-back is one of the first that is perceived. Consequently this sound contributes to the conscious and subconscious perception of product quality and the personal rating of like or dislike by the customer.

1.1. Purpose

When releasing the outer handle of the door of a passenger car, it snaps back with a transient sound. In order to give a pleasant premium door handling experience the impact needs to be medium low in level but primarily containing low frequency content. To be able to compare different designs of handles and their rubber bump stops, a test rig and method need to be developed. It will also be used to set requirements on component level to suppliers to be able to evaluate the sound of the handle in an earlier stage of design, independently from the door and the car.

1.2. Objective

The aim of this work is to develop a test rig, which can be used by the supplier to pre-evaluate handles in terms of sound quality. In the ideal case an objective evaluation of handles in the rig will correlate with the subjective impression when assembled to a door and car. A further target is to also elaborate a quantitative relation between in-situ and rig setup in terms of level, frequency components, transfer function etc. So the aim is to get a test rig, in which any handle can be pre-evaluated independent from the door and the car to receive the handle from the supplier in an acoustical pre-designed condition and adjust the door to it.

1.2.1. Proposed approach

Due to the available time the test is limited to one type of handle for the Volvo cars which will additionally be modified in several ways. For comparison, two good sounding competitor handles will be taken into account as well. In a first step it will be elaborated, how far a car door can be simplified in a rig in a way that it is still comparable qualitatively, i.e. rated in the same order by customers when assembled to a vehicle. Several measurements will be performed in order to also rate the rig quantitatively. Recordings will be taken for each setup to receive the rating of perception (listening tests). Additionally the sound radiation will be measured and the transfer function of the handle, the door and the rig. In the end all results will be compared and requirements will be specified. According to those the supplier will be able to pre-evaluate good quality handles in future.

2. Background

The door handle snap back sound is composed by the construction of the door, the construction of the handle and the interaction of both. When it comes to sound evaluation of the door handle on car manufacturer side, it is often the question if the main root of an occurring sound design problem can be ascribed to the door, the handle or the interaction of both.

To be able to detect and improve that in an earlier stage and more specific, the systems ″door″ and ″car″ can be regarded separately to a certain extend. If the handle itself fulfils certain requirements from supplier side, which are elaborated in this work, it can be focused on the door or the transfer path between handles and door for further improvements.

Generally there are of course other design solutions available for handle snap back reduction, like e.g. silicone dampers, which deliver very good results. But the aim in the present case is to basically keep the original design and improve it. Last but not least this is also a question of cost efficiency.

2.1. Research on car doors

In literature numerous studies can be found which are related to the sound of the doors of cars. Analyses are done on the door opening sound, many about the door closing sound [1][2][3], also the sound of the electric power window is of interest [4] and in the region of the handle mainly the locking sound. However, it can not be found much about the snap back sound of the handle.

2.2. Sound quality and sound design

The sound quality of a product is a mixture of the perception of the product and its actual noise. The perception is not only influenced by the noise but also of haptic or visual impressions and thus also of the expectations the consumer has of a product [5]. This can mean, that a purchaser expects a razor not to sound like a hair dryer, but also an expensive car not to sound cheap. And what cars are concerned, a great effort is put into sound quality engineering to be able to fulfil the customers expectations and not to risk his conviction in the dealership because of little details which might attract attention.

The door handle is one part of the acoustic image of the car. It is expected to make a sound, but it has to be the expected sound. The sounds of accessories like the handle, the seat adjuster or the door closing are counted to the indicators for sound quality whereas the engine sound or the road noise specify character or comfort. Furthermore the sound of the door handle is a passive one, which means it is only produced when it is touched, unlike operating or signal sounds, which are produced by the product while running [5][6]. But all of them contribute to the unmistakable brand sound. Since they all have the same function, the sound becomes the distinctive quality criterion [7].

The main issue with sound quality engineering is the translation between what a customer perceives and what that means in terms of physical values like e.g. sound levels for the engineer. The process that gives an understanding of sound and vibration of a product can be split in five parts: assessment, measurement, diagnostic, countermeasure and future design [8]. The general questions herein are: How does the product sound and vibrate? How can this be quantified physically? What is the root cause of this and how can it be affected? And last but not least, can sound and vibration quality be predicted for future products with help of this process? With these questions in mind and with help of listening test a target sound is set and the physics of the product is changed in order to closely meet this expected sound [7].

On the way to obtain sound quality metrics and threshold values, two ways of measurement and assessment have to be correlated. One is the subjective characterization which results from jury testing and ranking of sound recordings. The other one is the objective characterization which results from signal processing and sound quality metrics computation of the same recordings [8].

Generally it has to be kept in mind, that sound design is not alone a matter of satisfying customers. It has to match criteria of different fields in the process of development and assessment, see figure 2.1. This is in the present case also cost efficiency, which means easy design and implementation and includes in the overall understanding also issues like environmental compatibility [10].

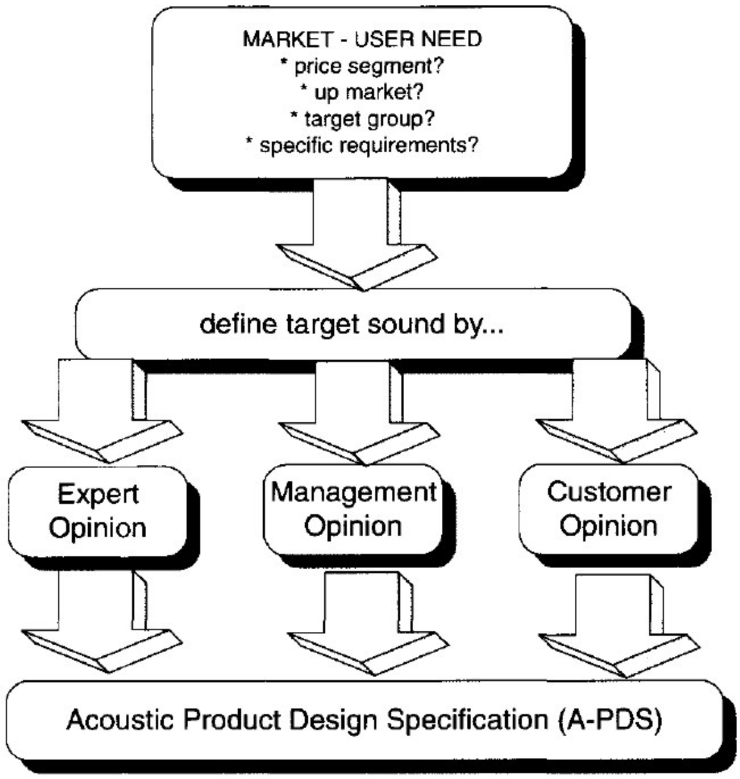


Fig. 2.1.: The way to reach a target sound [9].

2.3. Human perception

2.3.1. Ear

The human hearing works like all other human senses in a logarithmic way (Weber-Fechner law [11]). That means a doubling in perceived intensity is caused by an exponential increase of actual intensity of the stimulus. Therefore the analysis concerning the hearing perception is plotted with logarithmic scales.

The hearing ability of humans basically covers a range of 20 to 20000 Hz. But the sensitivity of the human hearing is not the same for the whole frequency range. As figure 2.2 shows, the most sensitive area is located at a frequency range of 2 to 5 kHz and it is decreasing the lower or higher the frequency gets. The human speach is also located in the range of high sensibility from around 200 to 7000 Hz [12].

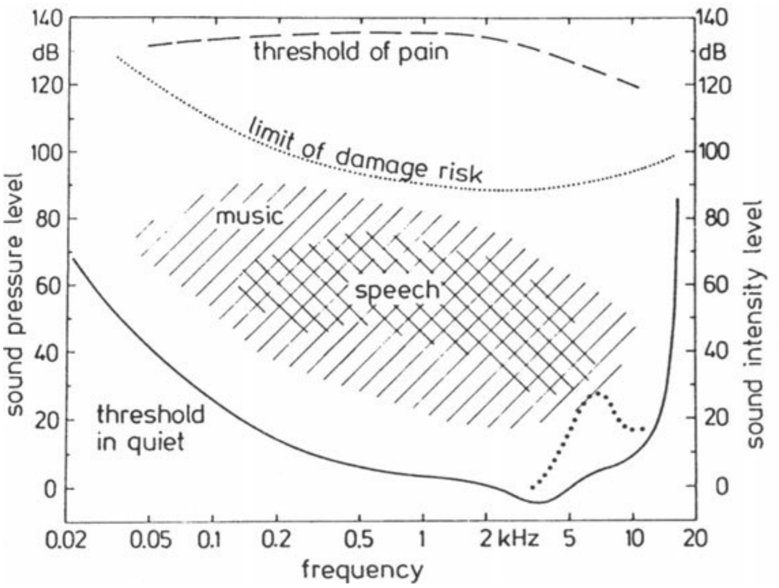


Fig. 2.2.: Map of the human hearing ability [12].

2.3.2. Neuroscience

Perception does not only have to do with the ability of hearing, but also with information processing and selection in the brain [13]. If a sound attracts attention and how a sound is assessed, is also depending on experience, on expectation, on cultural and social context and last but not least on emotions [14]. This fact is used for neuroscientific marketing research where sound design can be counted in as well [15]. If designers and manufacturers are able to understand how the human brain works, how decisions are made and what people like and especially why they like or dislike something, they are able to better understand the customers and match their expectations of the product [16].

2.4. Listening tests

A common and easy way to directly obtain what customers expect or which opinion they have about a sound, is to directly ask them in listening tests. There are different types of tests which are aiming for different types of results. When deciding on a test form it has to be clear beforehand, what is intended to be found out, to put up the right questions.

Subjects' experience should be appropriate. They should not be too naive, to be able to distinguish sounds, but not too expert to not overrate customers expectations. They should have product experience, but not be immune to evaluate it unbiased. The best is to use actual costumers. The test subject group should consist of a representative demographic mix, as well as gender mix (that does not mean equal, just representative). For simple evaluation tasks, which are those who require little training or no training, 25-50 expert listeners are needed or 75-100 unexperienced listeners respectively. In general it is the more the better [17].

The test environment should be comfortable for the subjects, which counts for the look, the temperature, the headphones, the light, the ambient noise etc. Any kind of distraction is to be reduced in order to keep the participants concentrated on the task. Depending on the type of test, it can be conducted in a group or with single persons. In case of a group it has to be made sure that the interaction between the participants is minimized [17].

The playback is supposed to be an original representation of the sound, so that the listener can feel like being in the situation he hears. This is usually realized with binaural recordings with an artificial head and a playback with high quality headphones. The sensitivity and the equalization settings should be same for all recordings and they should be presented to the subjects via calibrated headphones or loudspeakers at the correct volume. The samples should be recorded with the lowest needed range to achieve a good sound to noise ratio. Furthermore all recordings have to be consistent, i.e. equipment and settings have to be the same and the action, here the snap back of the handle, has to be performed in the same way and recorded from the same place, ideally the place where the consumer would be under normal use conditions [17].

The test persons have to be instructed well before performing the test, to feel confident while giving answers. This instruction should be written down and also be presented orally. It can be illustrated by additionally showing a picture or a video which explains the listening situation. The answers can be provided in a mask on a computer or written down on an answer sheet. Both options should also include a statistical part with personal information about the listener. However, participants must not be forced to give this information. It has to be up to the own decision as well as aborting the test at any time. The whole test procedure has to be conform with the ethical principles for medical research involving human subjects [18].

3. Theory

3.1. Semantic differential test

Various types of listening test designs exist, out of which the most suitable one has to be chosen. In order to obtain a ranking of the sound files in question, a pair comparison test can be used. Hereby a row of sound pairs is presented to the listener, who has to decide which one of the two he/she prefers. The preference can be connected to a certain attribute like "annoyance". This test can be conducted as a one sided or a two sided test. The two sided option includes the counter question if sample B is preferred over A to if A is preferred over B. The one sided option only asks in one way. The disadvantage of this test is that it can become quite long, depending on the number of samples and on the number of requested attributes. A good solution in this case is delivered by the semantic differential test. The listeners rate the samples one by one according to different attributes on a bipolar scale. The attributes on both sides of this scale have to be chosen carefully. It is recommended to use common vocabulary and not engineering vocabulary and to make sure that opposite adjectives can be clearly and easily distinguished to obtain meaningful results. This method provides a differentiated sound profile out of which it can be derived why a sample was rated better or worse than another one and to which extend [17] [21].

3.2. ANOVA

The evaluation of semantic differential tests is usually done with an analysis of variance (ANOVA). It can be carried out as a one-way analysis or n-way analysis, with respect to one or n attributes. This analysis works with the assumptions that the distribution of the scale values is normal and that the standard deviation is equal. The ANOVA compares the mean values of the sounds and determines if they are significantly different. However, it does not give a statement about which sounds differ, only whether they differ. An F-test is used to check if samples differ in terms of variance, which gives an information whether the difference is based in the group or between the groups. To test if the assumption of normal distribution is correct, a probability value is calculated. A critical value of usually 0.05 is defined. If the p value is smaller than the critical value, the assumption can be rejected, which means the data set is statistically significant [17].

3.3. A-weighting

In order to adjust measurement results to the perception of the human ear, different types of frequency weighting can be used. The most common one is the A-weighting. It was developed out of the curves of equal loudness, see figure 3.1, which show how loud a tone of a certain frequency and level is actually perceived analogue to the sensitivity of the human ear. Applying spectral A-weighting on a measurement, rates the results less towards the low and high frequency regions. The A-weighting function can be seen in figure 3.2.

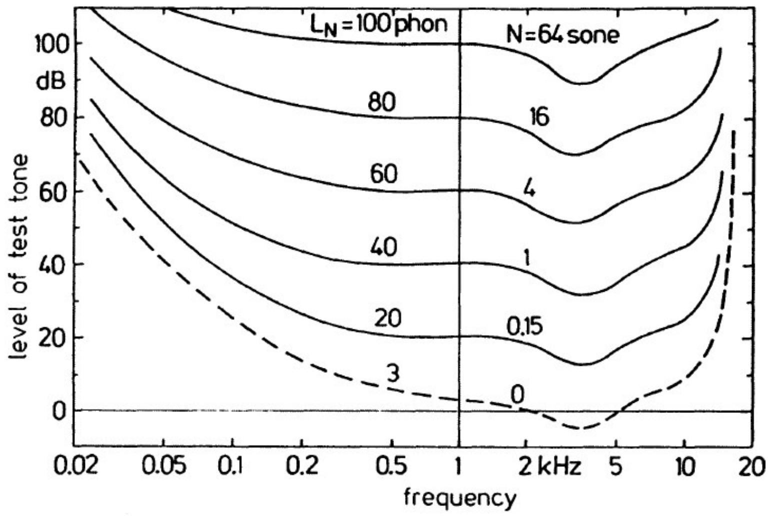


Fig. 3.1.: Equal loudness contours [12].

3.4. Sharpness

The sharpness of a sound plays an important role in the evaluation of sound quality. The perception of sharpness results from a certain relation between the low and high frequency content of a sound. Its effect on the sound quality can vary from powerful to aggressive, also depending on the purpose and expectation of the sound. Sharpness can be reduced by adding low frequency content, what increases the total sound level at the same time, or by reducing high frequency content [7]. Figure 3.3 shows a frequency spectrum for a less sharp sound (left) and for a sharp sound (right).

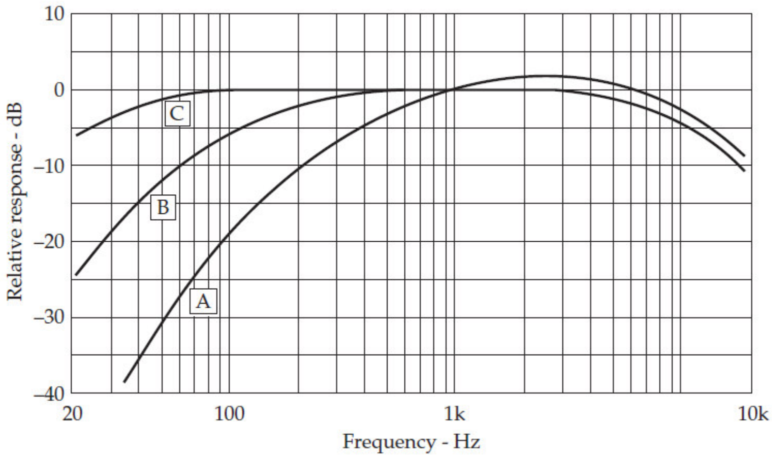


Fig. 3.2.: A-, B- and C-weighting functions [19].

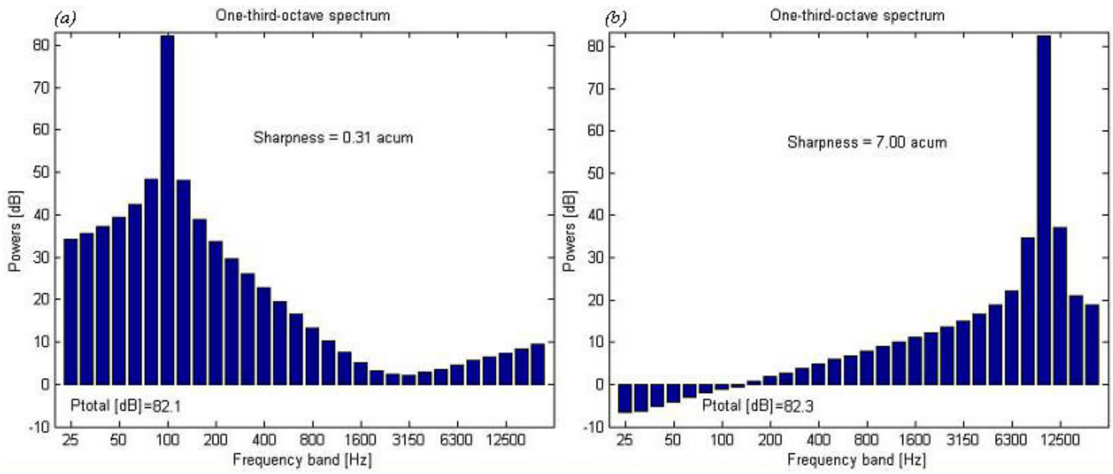


Fig. 3.3.: Frequency spectra of low and high sharpness [20].

3.5. FFT analysis

The DFT (discrete Fourier transformation) analysis is a mathematical way to receive a discrete frequency spectrum of a sampled time domain signal. The fast form of it, which needs less computational effort by making use of the two's complement coding, is the FFT (fast Fourier transformation) [23]. Since the FFT initially requires a finite time signal, a window function has to be applied. The simplest one is the rectangular window, which basically just cuts the time signal. The length of the time window has an influence on the resolution in the frequency domain. The following relationship applies: block length = number of samples / sampling rate, which means in consequence, the higher the resolution in the frequency domain, the lower it is in the time domain and vice versa [22].

4. Developing test rig and method

4.1. Preliminary consideration and boundary conditions

4.1.1. Test location

All measurements and recordings are conducted in the new semi-anechoic chamber in PV16 of the NVH department at Volvo Cars premises in Torslanda Gothenburg Sweden.

It is taken care that no external reflections from the ground or other objects can affect the measurements. For the listening tests, the snap back sound of a real handle mounted on a real car door is recorded. In this case the sender and receiver are in the natural position, which can lead to (natural) reflections from the ground and the car surface.

4.1.2. Test objects

The Volvo S60 handle design is the one under closer examination. It is tested both in the original version and with certain modifications regarding impact reduction or other modifications. Details about the approaches are specified in section 4.2. Additional tests are carried out with a competitor handle of the Audi A6 and with an own competitor handle of the Volvo V70. In order to keep the listening test limited, the number of modifications is kept small.

The measurements are conducted on the front door of the driver side and of the passenger side. The tests are carried out with all handle parts that can affect the snap back noise: the outer handle and the inner mechanic unit the gasket and the lock cylinder or the place holder.

4.1.3. Handle release process

The stroke position is taken as release position for every measurement. To ensure the same release position every time, a rectangular piece of plastic with an attached string is taken. One side length of this plastic piece has exactly the size of the distance between handle and gasket when the handle is fully pulled. An extra spacer has to be used for each stroke position and for each type of handle. In the present case the spacer for the S60 handle has the dimensions 37 x 27 x 1 mm.

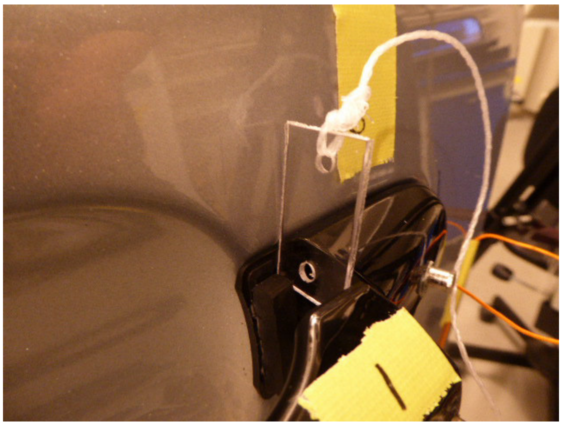


Fig. 4.1.: Start position of each measurement.

For the measurement the spacer is clamped between handle and gasket and then quickly pulled out with the string.

4.1.4. Setup

The main approach for the design of the test rig is to create it as simple as possible and as independent as possible. In the ideal case this rig can be used by any supplier or car manufacturer to test any arbitrary handle independent from the car, the door or the brand.

There are a few requirements, the rig has to fulfil. From the practicable point of view, it should be designed in an easy way, in sense of reduced to the main functions. It should have a simple structure, not a door structure, to be independent from any car or door. If a plate is used for the fixation of the handle, it should have recesses at the same place and of the same size as the original door panel has. Furthermore the plate should be of the same thickness as the door panel to fulfil the original mounting conditions. Here it can become the case, that different rigs are needed for different types of handles.

Fixation

From the measuring point of view it should be able to fix the door adapter with rubber bands in a room or a bigger rig frame. Here the weight of the whole construction has to be taken into account. On one hand only sound and vibration of the handle itself shall be measured, not the one of the rig. On the other hand it has to be a stable setup to take the weight of the handle construction.

Therefore a second approach is to mount the door adapter in a solid rig. In this case the rig is always the same and the adapter is unique for every type of handle.

The difficulty for both approaches is to ensure that the eigenfrequency of the fixation either the solid or the rubber band solution is considerably outside the frequency range of interest. Another important thing for the design of the rig is, to ensure the performance of reproducible measurements.

Door adapter

From the acoustical point of view the influence of the rig on the measurement should be minimized. So it is either to avoid the rig or the sheet metal to radiate itself or to take the radiation of the rig as a reference for all measurements and normalize all measurement to this rig.

Two promising approaches are tested in this study; a metal sheet in A4 size (VersA) and metal layers only of the size of the gaskets which are introduced as placeholders for the door (VersB).

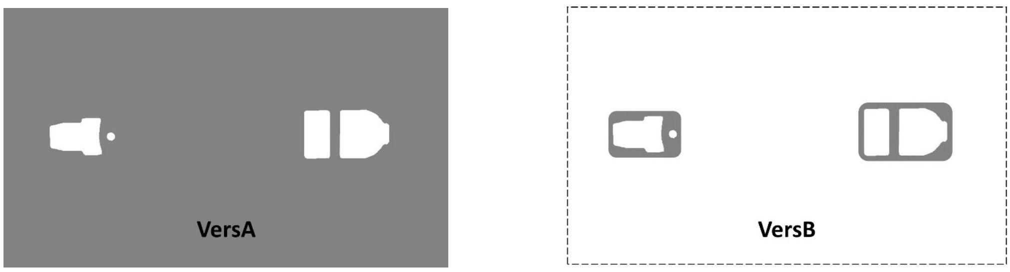


Fig. 4.2.: Sketch of the metal door adapters.

The disadvantage of the metal sheet is its own radiation and its own resonance frequencies, which can affect the measurements of the handle snapback. The advantage on the other hand is the possibility to place accelerometers not only on the handle itself but also on the metal sheet and figure out, how the surrounding of the handle will be affected by the snapback and if that might have a correlation to the subjective impression. In both cases the metal has to be curved at the edge of the grip cavity, to follow exactly the contact surface of the underlays and the top part of the handle.

A further description of both approaches as well as the chosen fixation will be given in

Gaskets		
name	description	thickness [mm]
G1	very thin rubber	0.7
G2	thin rubber	1.5
G3	thick stiff rubber	6
G4	two pieces of thick rubber	1.5
G5	curved rubber sideways	4
G6	curved rubber upright	9
G7	metal plate on thin rubber	1/1.5
G8	cut off original bump stops	0
G9	original	1

Table 4.1.: Overview of gasket variations

measurement section 5.2.

4.2. Modification of the handle unit

The modifications, which are done in this study, have the purpose to primarily deliver different snap back sounds. The design criteria concerning block dimensions, i.e. a plane handle surface in zero position, are not of importance. It is not the aim to create a realistic design solution for a high quality snap back sound but to find a physical parameter, which relates the objectively measured and the subjectively perceived rating to each other. This is realized with producing a great variety of snap back sounds, in order to enable and simplify a differentiation between the sounds in the listening test. Once a correlation is found out, requirements can be set, which have to be fulfilled by the designers.

<u>Gasket</u>

Different snap back sounds are created by gluing rubber of different thickness, stiffness and shape at the position of the gasket where the original rubber bump stops are placed. Additionally it is a piece of metal glued at this position on one gasket and for one modification the original bump stops are just cut off. The different modifications are shown in Table 4.2.

Handles		
name	description	weight [g]
H1	standard	70
H2	keyless without electrics	70
H3	keyless original with electrics	110
H4	keyless (with electrics) and additional weight	185

Table 4.2.: Overview handle variations

Handle

Another modification is the variation of the mass of the outer handle. Two handle variations are available, the standard version, which is the lightest, and the keyless version, which weights 40 g more due to the integrated electrics. One heavier version is created by gluing weights of in total 75 g onto the keyless handle. The handle modifications are shown in Table 4.2.

The available measurement car of the type S60 was coming with keyless handles. To not have to disassemble the whole door for changing from keyless to standard type, the keyless version without electrics was used. So the plug could be connected but the handle had the same mass as the standard version.

Pictures of both the handle and the gasket variations can be found in Appendix A.

4.3. Equipment

The equipment that is used for the measurements is listed in the following:

- Software Artemis Suite 7.1
- Software Artemis Classic (only for conducting the listening test)
- Software HEAD Recorder 7
- Frontend SQLab II
- Dummy Head HMSIII incl. stand
- Accelerometer Brüel & Kjær (sensitivity: 10.05 $mV/m/s^2$)
- Accelerometer Brüel & Kjær (sensitivity: 0.3125 $mV/m/s^2$)
- Accelerometer Dytran (sensitivity: 1.05 $mV/M/s^2$)

- Accelerometer PCB (sensitivity: 0.5919 $mV/M/s^2$)
- Vibration Calibrator Brüel & Kjær
- Cables
- Cars: S60, V70, Audi A6
- Handles according to 4.2
- Metal plate according to 4.1.4
- Metal cut outs according to 4.1.4
- Microphone stand
- Ordinary rubber bands
- *Betadamp 85399*: adhesive constrained layer vibration damping
- Plastic place holder inkl. string according to 4.1

5. Measurements

In the following, the different selected approaches are presented. In total all possible combinations of handles and gaskets were measured, but due to the available time and in order to not get a too extensive listening test the 12 most dissimilar ones in terms of perception and measurement are chosen to be evaluated further. Thus it is intended to obtain conclusive results.

All measurement positions have to be chosen with regard to reproducibility. So all positions and distances have to be specified unambiguously. Furthermore the positions have to be chosen in a way that the measurements show clear differences for the different modifications. Interesting points with respect to that in terms of acceleration are the one of maximum impact on the handle, the one of strongest expected coupling to the fix part of the handle construction and one of different expected coupling to the door panel due to the different modification.

So three measurement points for acceleration are chosen. Two on the handle and one on the door panel / test rig plate. Two more on the door panel were waived during test measurements due to high similarity to the ones on the handle. It goes without saying that in case of the rig version without the plate (VersB) only the two positions on the handle are used. Additionally the airborne sound is recorded with the artificial head. These recordings are also used for the listening tests.

5.1. Complete vehicle

The positions for the accelerometers are the following:

- Acc. 1: at the edge of the movable part of the handle at the position of the horizontal middle line
- Acc. 2: centered at the fixed lock part
- Acc. 3: vertically 2 cm above the edge of the handle and horizontally in the middle of the fixed part

The three accelerometer positions on the car are also shown in figure 5.1.

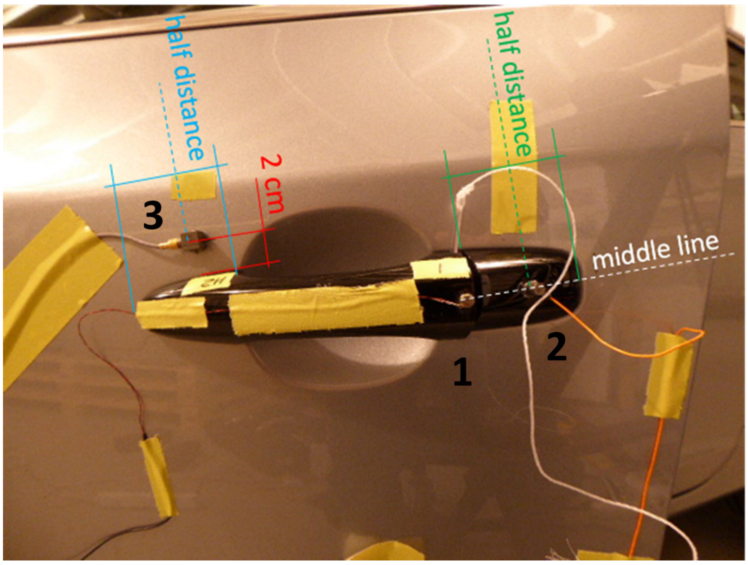


Fig. 5.1.: Measurement positions of the accelerometer on door panel and handle.

Position 3 is not possible to use for the Audi competitor car, since it is exactly the one where the keyhole is placed. Thus two other positions are tested, which are also located on the horizontal centre line of the lock part, one on the left and one on the right side of the keyhole, both at the middle between the edge of the keyhole and the edge of the component. Since the results do not show significant differences, only the inner one is used.

The artificial head is placed parallel to the x axis of the car, i.e. both microphones have the same distance to the x axis and the head is looking in y (driver side) or $-$y (passenger side) direction. The head is placed so that the microphones are on a height of 1.7 m above the ground according to the common measuring standard at Volvo Cars. The center of the middle pole of the stand for the head is supposed to be situated in 0.7 m distance to the intersection point of the split line of closed back and front door and the horizontal middle line of the handle. The so defined position of the artificial head is shown in figure 5.2.

For all measurements the door is opened to the first stop position. This position is chosen as the one of the natural handle release during the door opening process. Moreover it is a defined position.

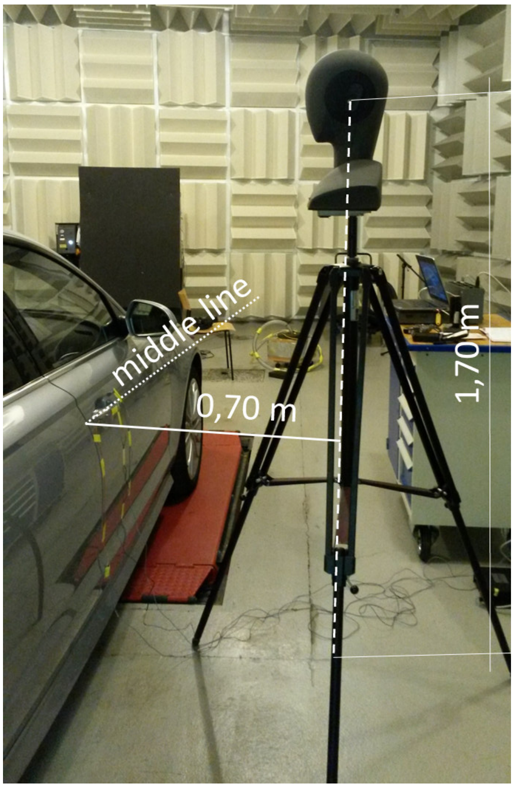


Fig. 5.2.: Measurement position of the artificial head.

5.2. Test rig

The test rig has to be build up in a way that the adapter-handle-construction is installed freely suspended. The focus is put on decoupling all structure borne sound which could be transmitted from the suspension or the mounting and influence the signal at the measurement points. It is to make sure that the eigenfrequency of the mounting system is clearly below the frequency of interest, which is 20 Hz in this case.

Due to the low mass of the test objects, a simple microphone stand is used for the suspension. Rubber bands are used to fix the handle construction on the stand. The rubber bands are fixed on the bracket of the handle, since the bracket provides many non moving spots to fix the rubber bands without drilling holes or damaging it in any way. Furthermore this way of fixation is independent of the design of handles from different manufacturers, so it can be transferred to any arbitrary handle. The choice of the rubber has to be made with respect to the frequency of interest.

For consistent measuring conditions, the arm of the microphone stand is put in horizontal position at a height of 1.65 m. The artificial head in this case is placed at a distance of 0.7 m of each microphone to the arm of the stand and the hight of the microphones is 1,7 m as for the measurements of the complete vehicle.

5.2.1. Rig version A

The test rig version A is a 0.7 mm thick metal plate, which is the thickness of the door sheet of the Volvo S60. The dimensions of the plate are the ones of the standardized A4 paper format. The handle is mounted on this plate like normally on a door. Therefore the original footprint of the handle has to be copied to the plate. The cut outs are produced by laser according to the original CAD drawing. The curvatures are pressed with suitable tools by hand. In figure 5.3 this plate is shown. Since there were no original CAD drawings available for the two competitor handles, these two were excluded for all rig measurements.

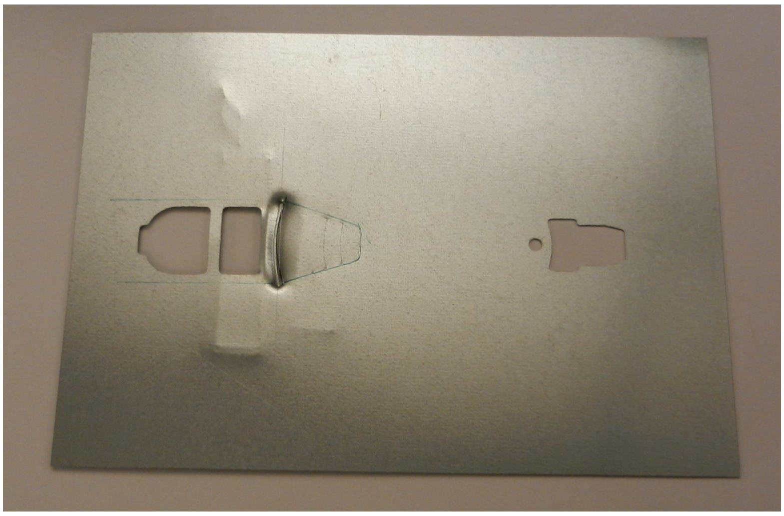


Fig. 5.3.: Plate for rig version A.

The accelerometers are attached here in the same positions as for the complete vehicle measurement. During test measurements the own vibration of the plate is reduced by attaching adhesive damping material to the plate in an asymmetric way, to interrupt possible modeshapes. The effect is checked by listening and evaluating the test measurements. This construction and suspension can be seen in figures 5.4 and 5.5.

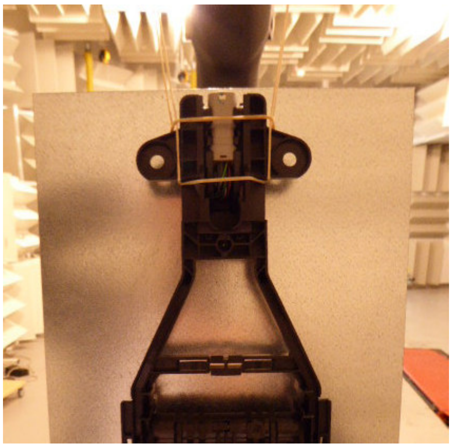


Fig. 5.4.: Suspension of the handle-plate-construction on the stand.

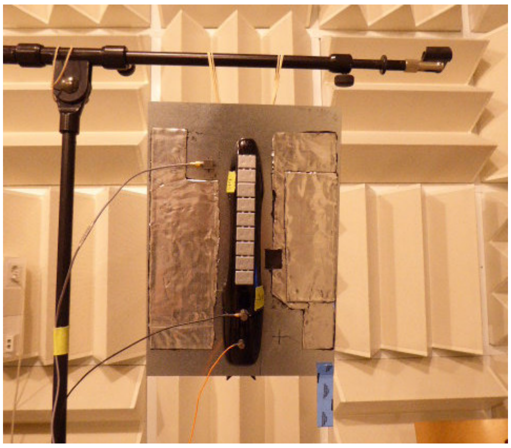


Fig. 5.5.: Setup with plate, handle, accelerometers and adhesive damping material.

5.2.2. Rig version B

The test rig version B consists of two metal layers of the same shape as the gaskets of the handle. The function of these metal layers is to provide mounting conditions and replace the door sheet only for the contact point in order to get a maximal door-decoupled testing solution. These door place holders can be seen in figure 5.6.

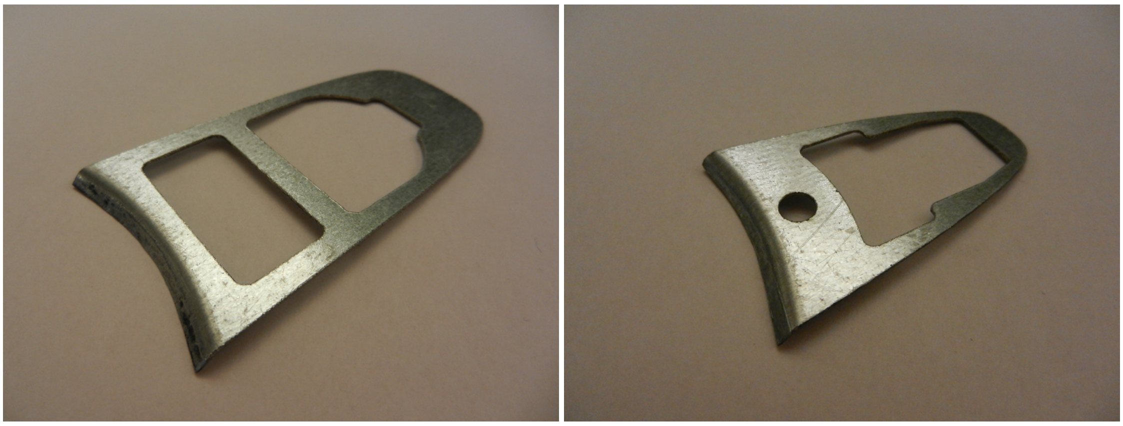


Fig. 5.6.: Metal layers for rig version B.

This setup is mounted in the same way as in version A with rubber bands on the stand, but in this case there are of course only the two accelerometers on the handle attached.

5.2.3. Settings

All measurements are recorded with the same settings. The recording time is set to a total duration of 3.0 s. This time includes a pre trigger of 0.5 s and a duration of 2.5 s. The threshold for the pre trigger is set to the acceleration of 7 m/s^2 of accelerometer 1 (the one on the moving handle). This threshold has been figured out during test measurements. The pre trigger time ensures that the recording starts 0.5 s before accelerometer 1 reaches 7 m/s^2. One advantage of this procedure is, that all files have the same length and the same general shape, which facilitates the analysis afterwards. The range of the artificial head is set to 110 dB(SPL).

5.3. Listening test

The second important part of the measurements is the listening test, since the goal of this study is to relate the objective measurements to the subjective perception of potential customers. Only the recordings of the handle at the complete vehicle are used.

To keep the listening test at a reasonable length, a total of 12 samples of all measured combinations are chosen, of which 2 are the ones of the competitor cars. The other 10 are mainly selected by distinguishability. It shall be possible also for inexperienced listeners to hear a difference between the sounds and rate them to each other. This selection is done by listening to all of the sounds beforehand. The selected files are randomized by labelling them from A to L. The randomization list can be seen in appendix B.

To figure out what customers perceive as high quality and to get an indication for the reason of this perception, the listening test is built up as a semantic differential test. The listeners are asked to rate all 12 sounds according to seven different attributes, each on a scale from 1 to 7. The main attribute that is asked for is quality. Other attributes are chosen with respect to determining what the listener relates to quality but also with respect to relating the outcome of the listening test to the objective measurements. To keep the test persons attention high, the attributes are not arranged in an obvious good-bad order but in a mixed order. Thus a biased correlation of the different attributes to "quality" should be avoided.

The test is conducted in the listening studio at Volvo Cars R&D site in Torslanda. The samples are played back via a calibrated system at the same level as they were recorded. So the participants listen to an aurally correct playback via headphones.

The test is conducted one by one so that every participant is able to listen to every sample as often as wanted. Furthermore there is no given order in which the samples are played back. Every listener gets an oral description/instruction of the test leader, who is also present and available for questions throughout the test. The test is performed by clicking on the samples (see figure 5.7) and rating them in the tables on the answer sheet (see appendix C). In average the listening test takes 20 minutes per person.

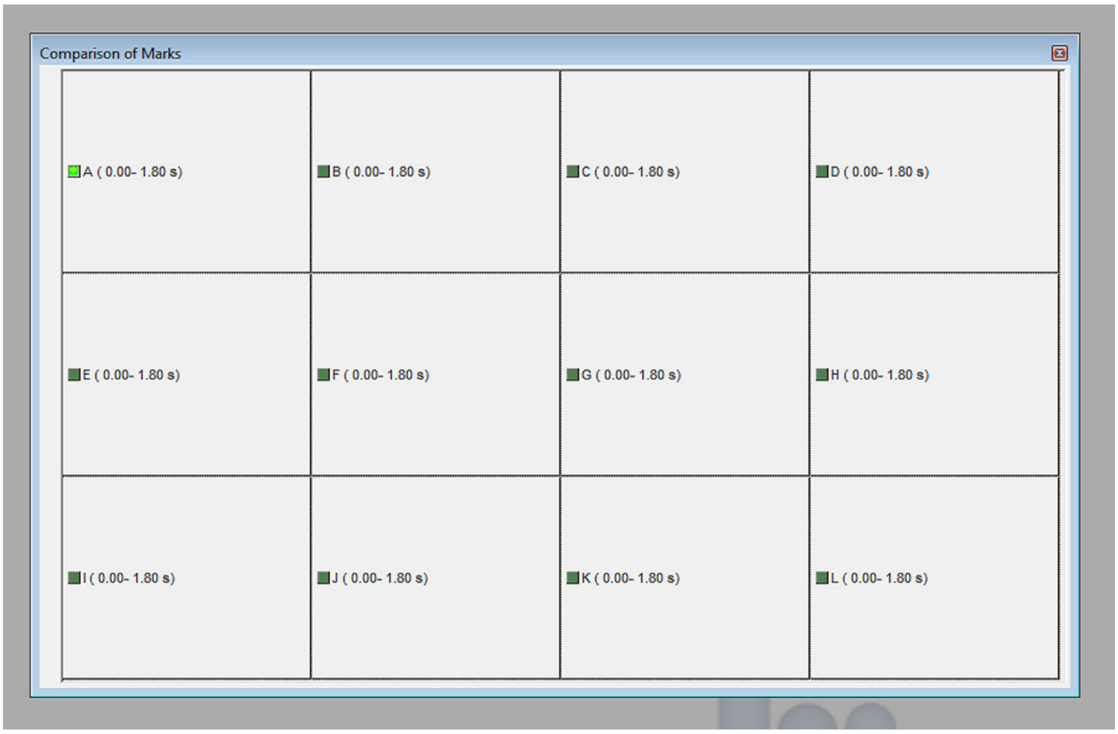


Fig. 5.7.: Screenshot of the listening test.

Statistical information

All participants were asked to voluntarily give some personal information about themselves. In total 27 persons participated in the listening test. Two did not provide any personal information. The age range was 25 to 57 years, the average age was 35.3 years. 19 participants were male, 6 female, 2 without specification. 17 participants were working at Volvo Cars NVH Center at the time of the test, 8 were working at another department, 2 without specification. 24 participants stated to not have any hearing disorder, 1 stated a hearing disorder, 2 did not give any information regarding that. 18 participants had experience with performing a listening test, 6 did not have experience, 3 without specification. Everyone was asked to rate him/her level of listening training on a 5-point-scale. 8 considered themselves as trained listeners, 6 as rather trained, 3 as neither of them, 4 as rather not trained and 4 as not trained, 2 did not give any specification.

6. Evaluation and ratings

6.1. Subjective evaluation

The listening test is evaluated with a one-way ANOVA (see section 3.2). In figure 6.1 the subjective ratings as the result of the listening tests are presented. For a better presentation and understanding the rating is switched (compared to the answer sheets) for certain attributes, e.g. 1 = high quality and 7 = low quality in the answer sheets is now 1 = low quality and 7 = high quality. Furthermore the attribute quality is taken as the reference, i.e. the samples are ordered on the x-axes according to their ranking of quality and the other attributes are shown in the same ranking in relation to the attribute quality. For a better overview, the graphs only show the mean values. The particular mean values and variances are shown in table 6.1. A tabular view of the particular rankings can be found in the appendix D.

The correlation factor of each attribute to the perceived quality is shown in table 6.1. The attribute strength does not show good correlation. This means either that strength does not have any relation to quality or that the participants did not know what is meant by strong and weak or that they had different ideas of it. The best correlation show suitability and pleasantness. The value of 0.98 for suitability could indicate, that the listeners did not distinguish between suitability and quality in this case. So quality seems to be already depending on suitable for a certain product/action. The result for pleasantness can be interpreted as one attribute of quality. The same might count for solidity in the case of the snap back noise, except from sample K. A tendency can be seen that a rather solid sound indicates low quality and a rather ringing sound high quality. However, it has to be stated, that all values (the upper and lower extremes excluded) lie in a small range of 3.58 and 4.74, which indicates that people could not decide how to rate this parameter. When looking at the variance of the evaluation of solidity, it shows continuously quite high values, which means, people did not agree with rating this attribute.

The two parameters loudness and sharpness, which can be put in a relation to the acceleration measurements, show good correlation. The correlation factor is higher for sharpness, but the variances are lower for loudness. Therefore both attributes seem to have a certain influence on the subjective perception of quality.

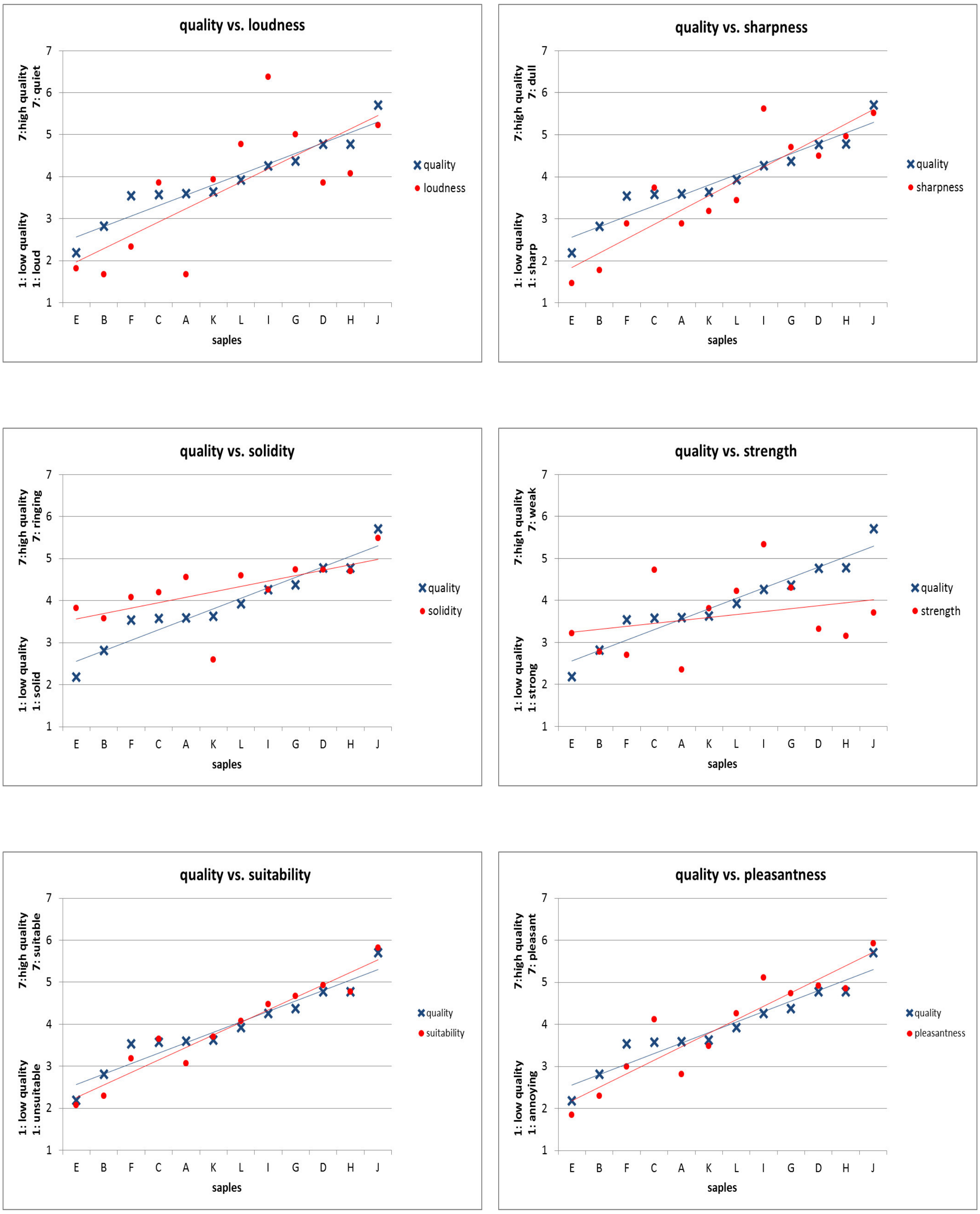


Fig. 6.1.: Mean values of the listening test evaluation. Note: The samples on the x-axes are ordered according to the rating of the attribute quality.

6.2. Transfer of listening test results to airborne sound measurements

For the objective evaluation an FFT frequency analysis as well as a level vs. time analysis is used. The parameters for the FFT analysis are chosen with respect to the handle snap back sound being a transient signal. The duration of the impulse is around 0.3 s, therefore a spectrum size of 32768 is chosen. With a sample frequency of 44100 Hz a block length of 0,743 s results, thus one block is sufficient for the analysis and no information gets lost when using a rectangular window. For a better presentation a third octave dB averaging is used to smooth the graphs. Furthermore the A-weighting function is applied. The level vs. time analysis is carried out with a spectral A-weighting and a manual time weighting with a time constant of 10 ms.

To figure out what the results of the listening test means in terms of objective values, a closer look is first taken at the microphone signals of the measurements on the complete vehicles, i.e. the signals which were presented to the listeners. In order to see clear differences, three samples are chosen. One of the best rated, one of the worst rated and one that is rated in the medium range. These are sample E as the one which is rated as the lowest quality, the sharpest and one of the loudest; sample J as the one which is rated as the highest quality, one of the dullest and one of the most quiet, and sample K which is rated in the middle in terms of quality, sharpness and loudness. For the evaluation of the airborne sound signals, left and right channel of the artificial head recordings are averaged.

In figure 6.2 both analyses are presented. The level vs. time analysis on the left shows that the peak levels correspond to the perceived ranking. In the FFT analysis a general level difference can be observed for frequencies higher than 270 Hz. Furthermore one main difference between the frequency response of these three samples is located in the region between 1 kHz and 2 kHz. This can be an indication for the difference in sharpness perception.

To verify these observations, one more sample of each category (good - medium - bad rating) is added, see figure 6.3. The order of the peak levels basically follows the quality rating of the perception. But although sample B and C have the same peak level, B is clearly rated louder as C in the listening test, which indicates, that loudness alone can not be taken as a measure of quality. When looking at the FFT in figure 6.3 the rating of sample C can be explained by comparatively high levels between 500 and 1000 Hz but

sample	quality		loudness		sharpness		solidity		strength		suitability		pleasantness	
	mean	var.	mean	var.	mean	var.	mean	var.	mean	var.	mean	var.	mean	var.
A	3.59	1.71	1.67	0.69	2.89	1.64	4.56	2.33	2.35	1.12	3.07	1.53	3.07	2.00
B	2.81	1.54	1.67	0.62	1.78	1.72	3.58	2.97	2.78	2.33	2.30	1.45	2.30	1.91
C	3.58	1.37	3.85	0.82	3.73	1.56	4.20	1.25	4.73	1.40	3.65	1.60	3.65	1.31
D	4.77	1.06	3.85	1.21	4.50	1.62	4.73	2.04	3.32	1.31	4.92	1.43	4.92	1.19
E	2.19	1.00	1.81	0.54	1.46	0.42	3.81	2.39	3.22	4.41	2.07	1.15	2.07	0.82
F	3.54	1.06	2.33	0.62	2.88	2.03	4.07	2.46	2.70	1.75	3.19	2.00	3.19	1.85
G	4.37	2.63	5.00	1.38	4.70	1.14	4.74	2.20	4.30	1.99	4.67	2.54	4.67	2.20
H	4.78	1.49	4.07	0.99	4.96	1.04	4.70	2.29	3.15	1.59	4.78	1.33	4.78	1.21
I	4.26	2.51	6.37	0.24	5.62	1.21	4.26	2.43	5.33	2.23	4.48	3.26	4.48	1.64
J	5.70	0.83	5.23	1.54	5.52	1.34	5.48	1.49	3.70	2.45	5.81	1.39	5.81	1.07
K	3.63	2.24	3.93	1.69	3.19	1.62	2.59	2.25	3.81	2.08	3.70	2.22	3.70	2.26
L	3.92	1.51	4.78	1.72	3.44	2.41	4.59	2.56	4.22	2.26	4.07	1.84	4.07	1.12

Table 6.1.: Mean values and variances for all attributes and all samples.

attribute	correlation factor
loudness	0.71
sharpness	0.91
solidity	0,69
strength	0.25
suitability	0.98
pleasantness	0.94

Table 6.2.: Correlation of each attribute to "quality"

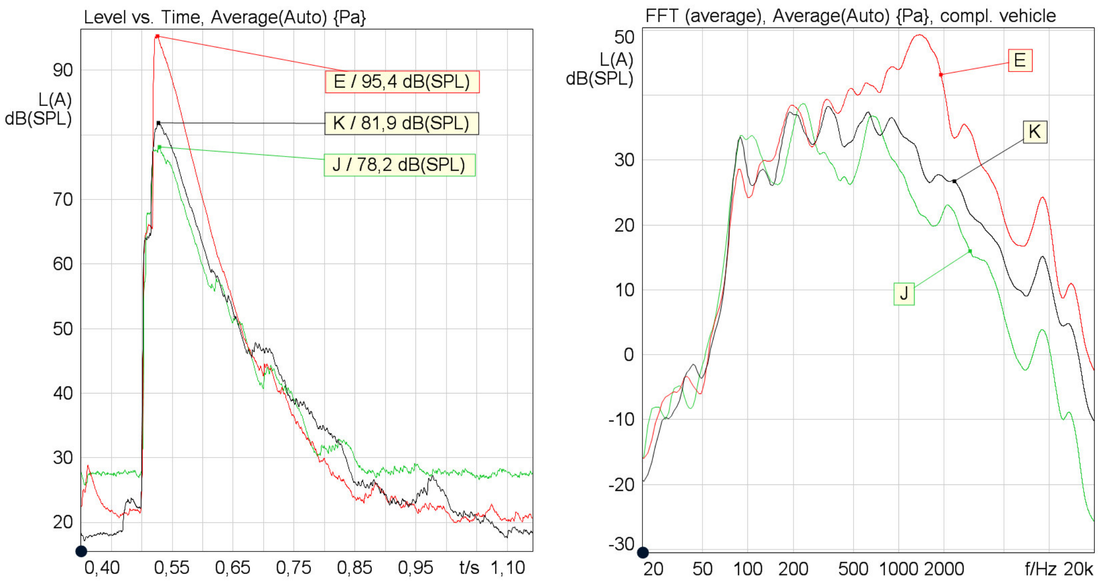


Fig. 6.2.: Level vs. time (left) and FFT (right) analysis of the averaged microphone signals of the samples J (good rated), K (medium rated) and E (bad rated).

at the same time a less pronounced peak between 1 and 2 kHz compared to samples B and E. Furthermore samples B and E are rated as the most sharp and samples I and J as the least sharp in the listening test, which is another indication that a peak between 1 and 2 kHz causes this perception.

To show the difference in loudness and sharpness perception in terms of frequency response, a selection of four differently rated samples is presented in figure 6.4. To the right of the graph a table shows the ratings of the listening test. For explanation, sample B is rated loud and sharp in the listening test, I is rated quiet and dull, A is rated louder than sharp and E sightly sharper than loud. When comparing the graphs for A and E it is noticeable that A delivers higher levels between 160 and 450 Hz but no peak between

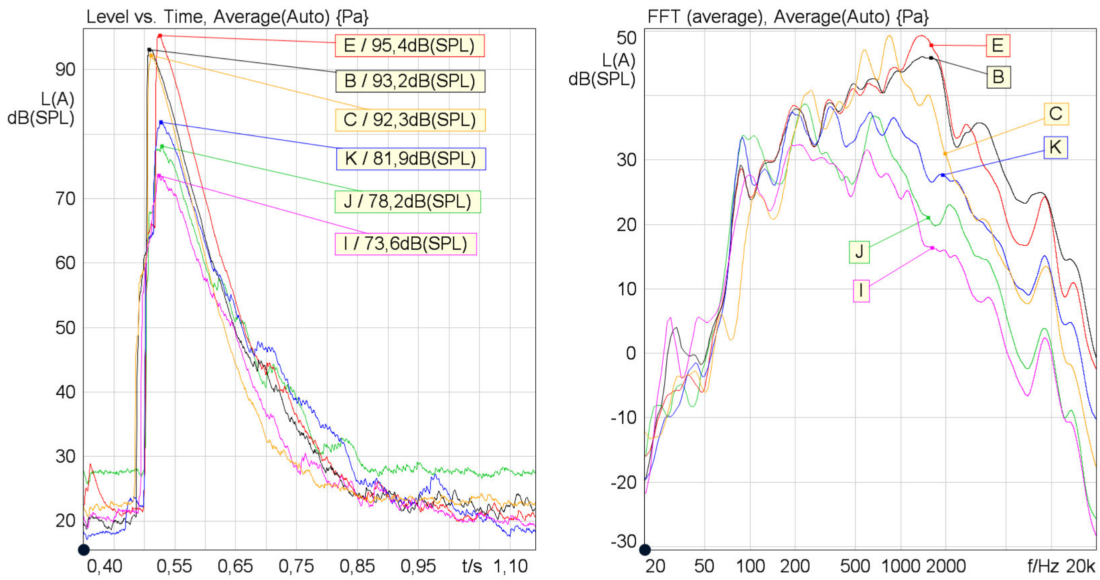


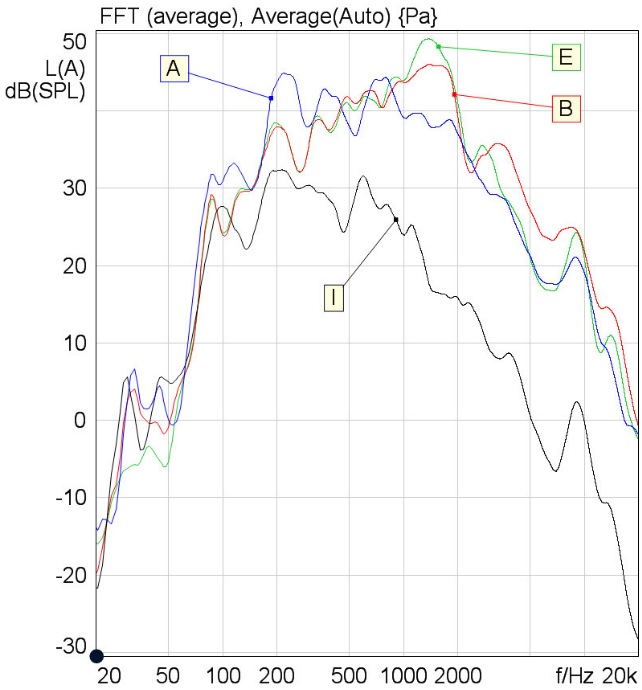
Fig. 6.3.: Level vs. time (left) and FFT (right) analysis of the averaged microphone signals of the samples J, I (sharp rated), K, C (medium rated) and E, B (dull rated).

1 and 2 kHz, whereas the level of E is more or less constantly increasing until a peak at 1350 Hz. Sample I, however, shows comparable low levels for 160 to 450 Hz, as well as no peak but decreasing levels from 600 to 7000 Hz.

6.3. Transfer of airborne sound measurement results to acceleration measurements on the complete vehicle

To transfer the observations of section 6.2 to the acceleration measurements on the complete vehicle, it is taken a look first on the samples J, K and E (good, medium, bad) as well. Figure 6.5 shows the FFT analysis of the measurements at all three positions compared to the averaged microphone signal (bottom right).

When comparing the three acceleration plots, it can basically be stated, that the same order of J, K and E as for the airborne sound and listening test evaluation can be seen in all of them in the frequency range of 450 to 3600 Hz (white in the plot). The indication for the different perception of sharpness, which was the range of 1 or 2 kHz for the airborne sound evaluation, can not be observed as clearly in the acceleration measurements. All of the graphs show a particular shape, but except for sample K in the figure of position 1, the main difference seems to be just the level of acceleration. To analyse this further, the two sharpest and two dullest rated samples are compared, which can



sharp	loud	sample
X	X	B
O	O	I
O	X	A
X	O	E

Fig. 6.4.: Left: FFT analysis of the averaged microphone signals of the samples A, B, E and I. Right: Corresponding sharpness and loudness rating of the selected samples.

be seen in figure 6.6.

At position 1 the level of acceleration is increasing for sample E and F until 1000 or 1400 Hz respectively and decreasing for higher frequencies, whereas sample I and J do not show a real maximum but more a plateau between 120 and 1800 Hz (J) or 50 to 700 Hz (I). At position 2 a similar observation can be made with two peaks at 850 and 1800 Hz for sample E and F, but with with a dip in between at 1200 or 1300 Hz, which indicates an antiresonance at this point. Sample I and J show more a plateau behaviour between 130 and 4600 Hz. Also at measurement position 3 the highest acceleration level for sample E and F is located at higher frequencies, 600 to 2500 Hz, than for samples I and J, 200 to 1000 Hz. However, position 3 should be interpreted with caution, since this measurement point is located on the door panel, which might have an own influence and different influence for different doors/models.

6.4. Transfer of acceleration measurement results on the complete vehicle to acceleration measurements on the test rig

In this section the findings from the previous one shall be transferred to the measurements in the test rig. First the results of the handle mounted on the plate will be examined, and in the next step the ones of the single handle measurements.

6.4.1. Measurements with the handle mounted on a plate

Figure 6.7 shows the FFT analysis of the sharp, medium and dull rated samples E, K and J of all three measurement positions on the plate, compared to the airborne sound analysis of the measurements on the complete vehicle. The peak in the curve of sample E between 1 and 2 kHz in the graph of the complete vehicle measurement which was determined to be the indication for the subjective sharpness perception could be detected in the analysis of position 1 and 2 as well. For position 1, it is located at 1 kHz, a second one occurs at 2200 Hz, for position 2 it is located at 2100 Hz. At position 3, the one on the plate, it can be seen a peak at 1100 Hz, but it is not that pronounced compared to the whole shape between 200 and 4000 Hz. Taking the frequency response of sample K and J into account, it can be stated, that the measurements at position 1 correspond to the one of the complete vehicle analysis the most, although the rather high level of sample K at 500 to 1000 Hz is not that convincing in terms of proving this analysis transfer.

Also for the measurement on the plate it is taken a look on the two extreme samples of the sharpness rating, see figure 6.8. Comparing the general shapes sharp vs. dull, the measurement at position 1 supports the previous findings the most. On one hand the previously mentioned peaks at 660 Hz (sample F) and 1 kHz (sample E) exist, on the other hand also the general shape shows a rising and falling part for the sharp rated samples and a kind of plateau shape 50 and 2100 Hz for the dull rated ones. This observation can not be made as clearly for the measurement positions 2 and 3.

6.4.2. Measurements with the single handle

For the measurements of the single handle only two accelerometer were used, the ones at position 1 and 2. Figure 6.9 shows the previously analysed samples for this setup. Similar to the measurements with the plate, the curve for sample E shows two peaks at position 1, here at 900 and 2250 Hz. Contrary to the measurement with the plate, the frequency response for sample K is not continuously falling from 700 Hz upwards. The plateau shape for sample J occurs here as well. Looking at the comparison of the two extremes (bottom), the observation of the two peaks and the plateau can be transferred to sample F and I as well. However, for position 2 (right side in 6.9) this statement is not true for sample K and I.

6.5. Reproducibility

To test the reproducibility of all the measurements that were made and evaluated in this study, all of them were conducted at least two times. A selection of five samples (E, F, K, I, J) is shown in figure 6.10. One plot is presented for each of the setups: complete vehicle (top left), handles in the plate (top right) and single handle measurement (bottom left). Two or three measurements of each sample in the respective setup are plotted. It can be seen that apart from small deviations, these measurements are highly reproducible.

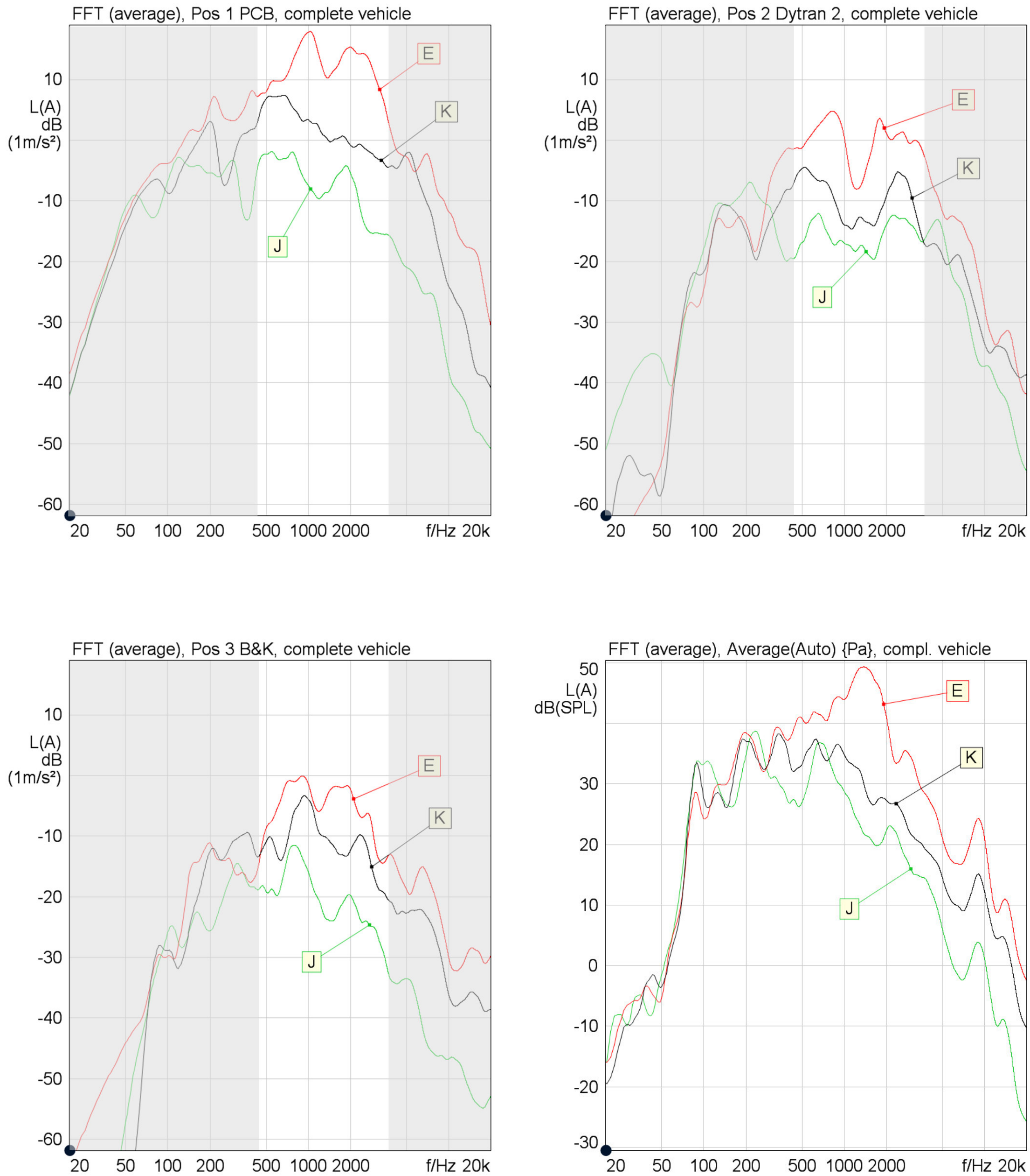


Fig. 6.5.: FFT analysis of the acceleration measurements on the complete vehicle of the best (J), medium (K) and worst (E) rated samples compared to the averaged microphone signal. Top left: acceleration at measurement postion 1, top right: acceleration at measurement position 2, bottom left: acceleration at measurement position 3, bottom right: averaged airborne sound signal of the microphone measurements.

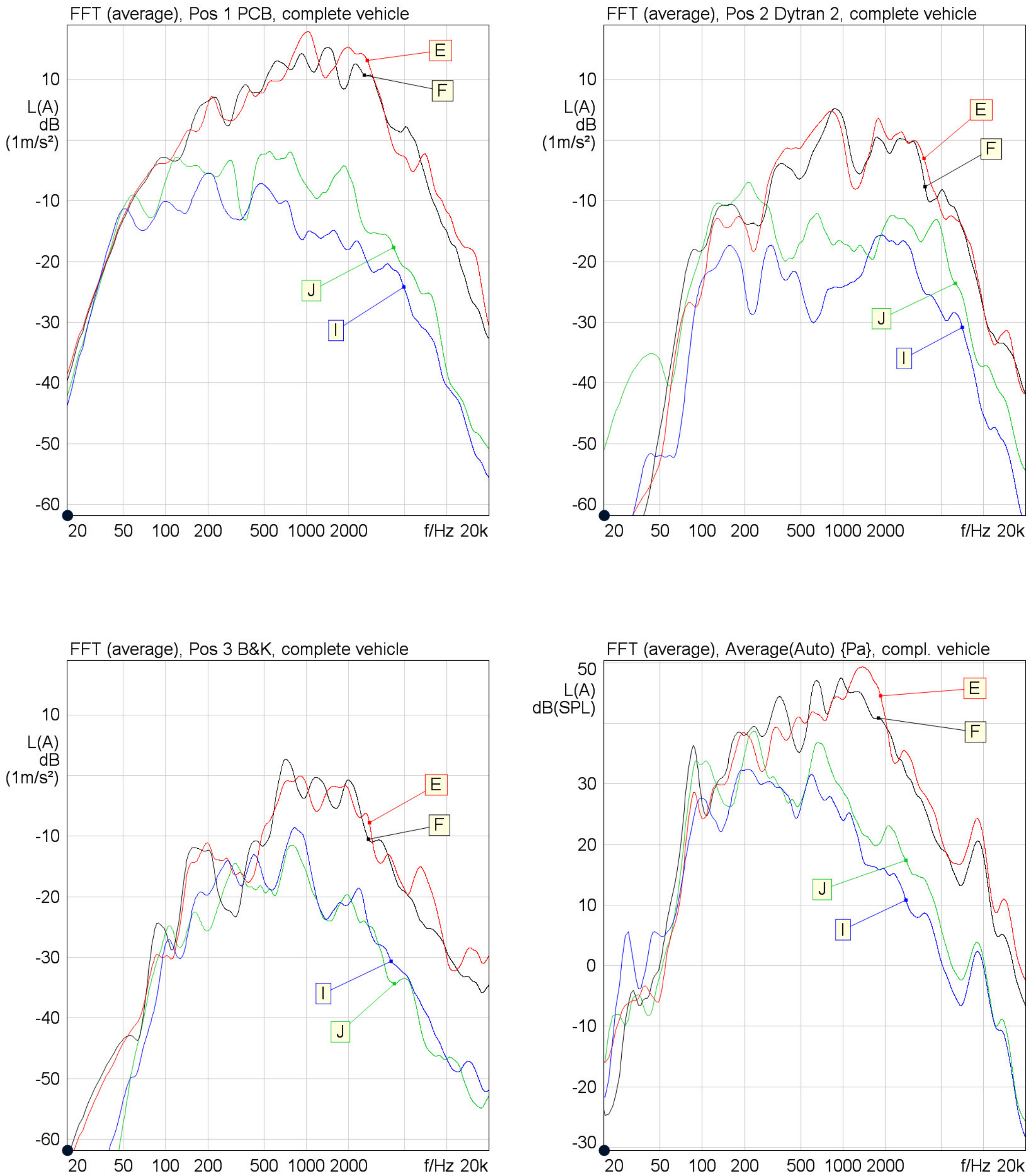


Fig. 6.6.: FFT analysis of the acceleration measurements on the complete vehicle of the two best and two worst rated samples in terms of sharpness, compared to the averaged microphone signal. Top left: acceleration at measurement postion 1, top right: acceleration at measurement position 2, bottom left: acceleration at measurement position 3, bottom right: averaged airborne sound signal of the microphone measurements.

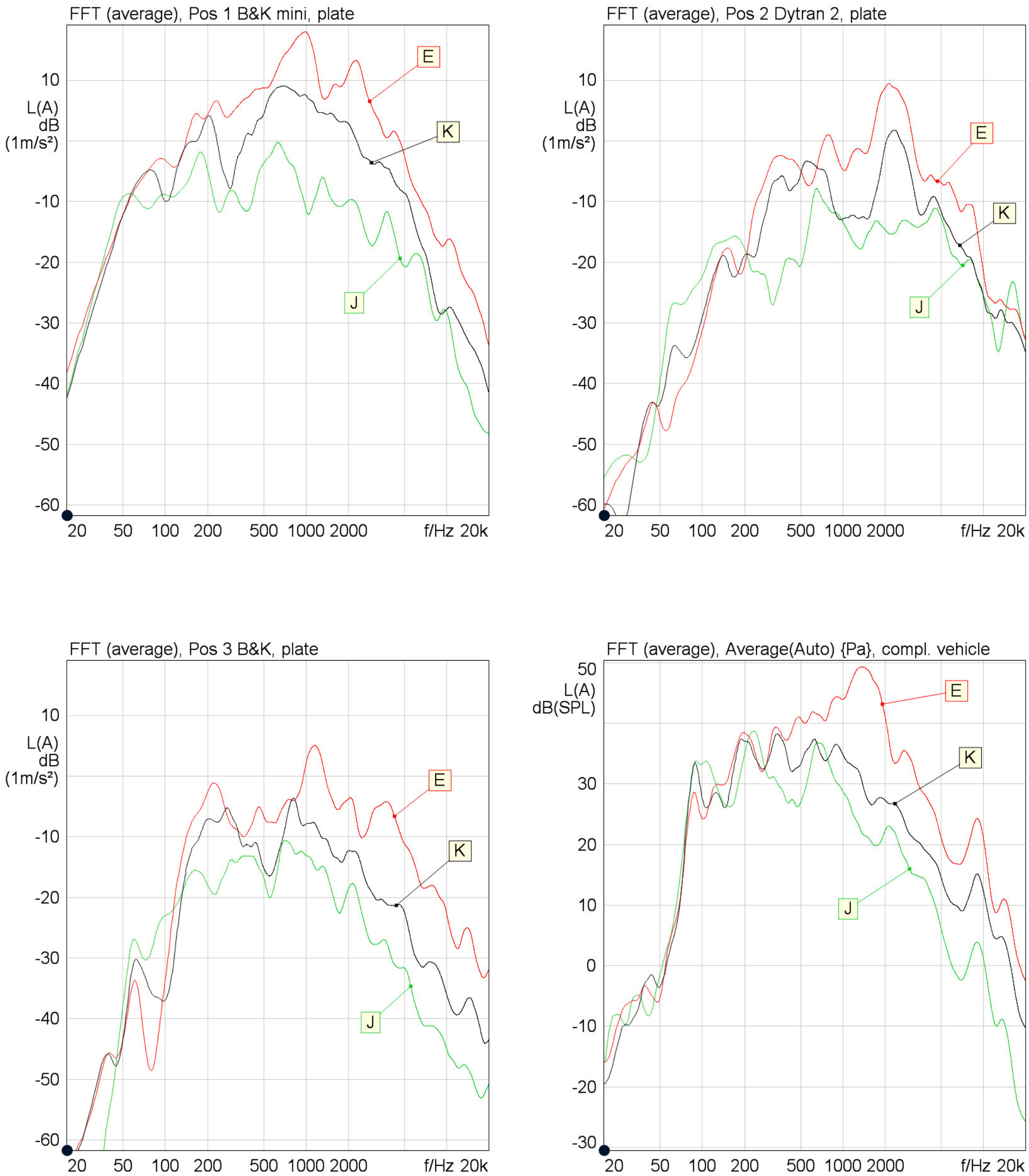


Fig. 6.7.: FFT analysis of the acceleration measurements on the handle mounted on the plate of the best (J), medium (K) and worst (E) rated samples compared to the averaged microphone signal. Top left: acceleration at measurement postion 1, top right: acceleration at measurement position 2, bottom left: acceleration at measurement position 3, bottom right: averaged airborne sound signal of the microphone measurements.

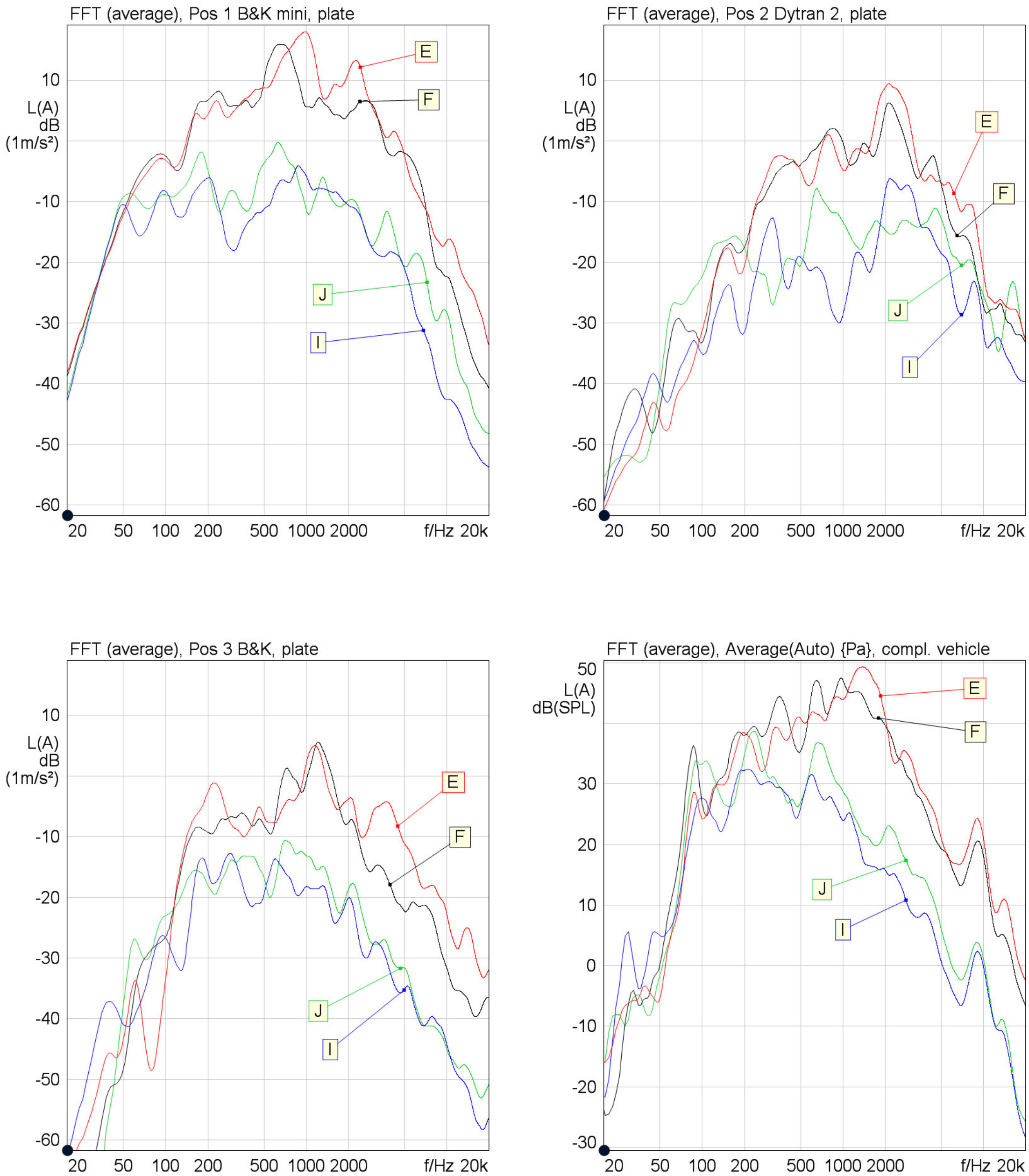


Fig. 6.8.: FFT analysis of the acceleration measurements on the handle mounted on the plate of the two best and two worst rated samples in terms of sharpness, compared to the averaged microphone signal. Top left: acceleration at measurement postion 1, top right: acceleration at measurement position 2, bottom left: acceleration at measurement position 3, bottom right: averaged airborne sound signal of the microphone measurements.

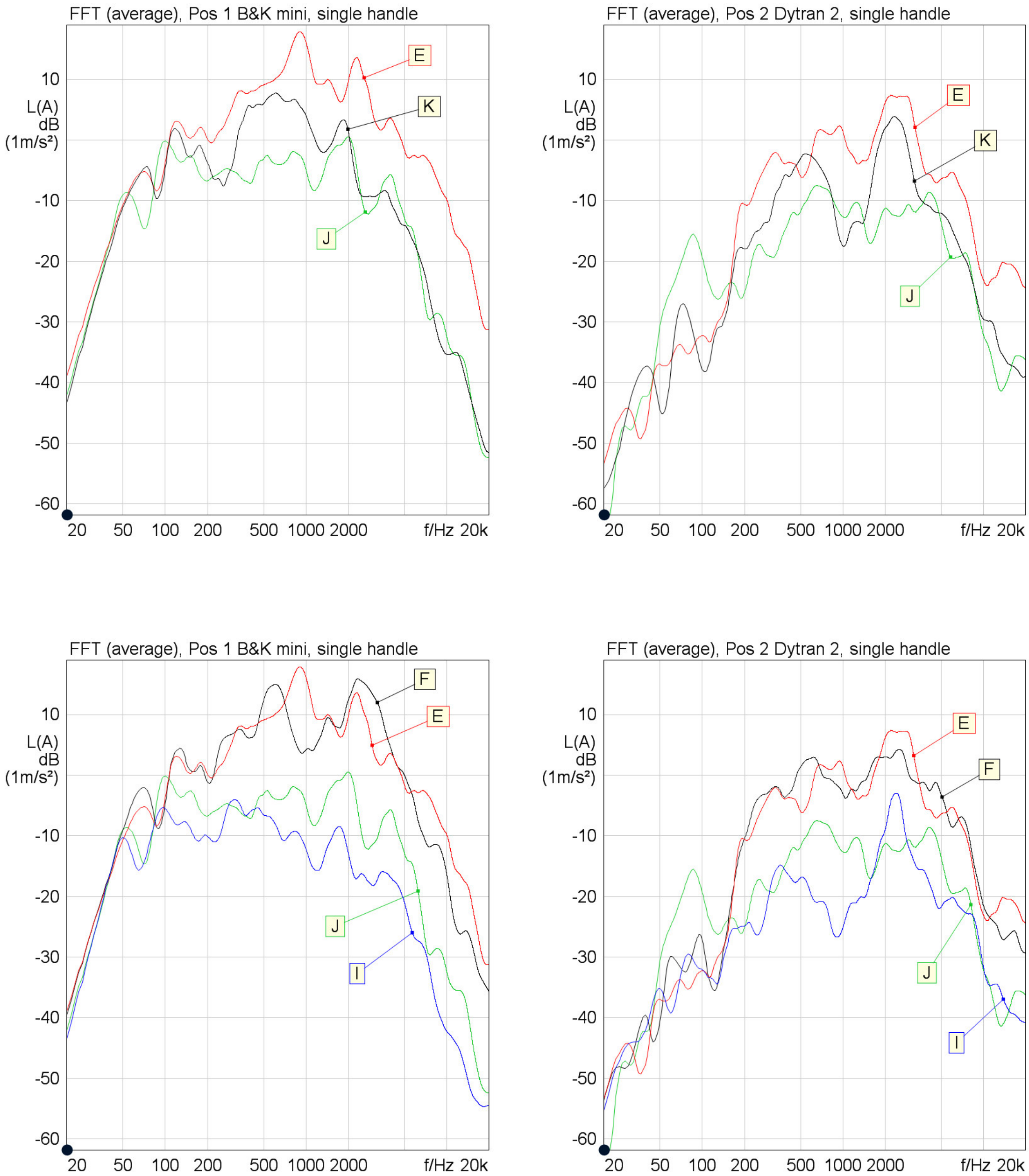


Fig. 6.9.: FFT analysis of the acceleration measurements on the single handle of the best (J), medium (K) and worst (E) rated samples (top) and of the two best (I, J) and two worst (E, F) rated samples in terms of sharpness (bottom).

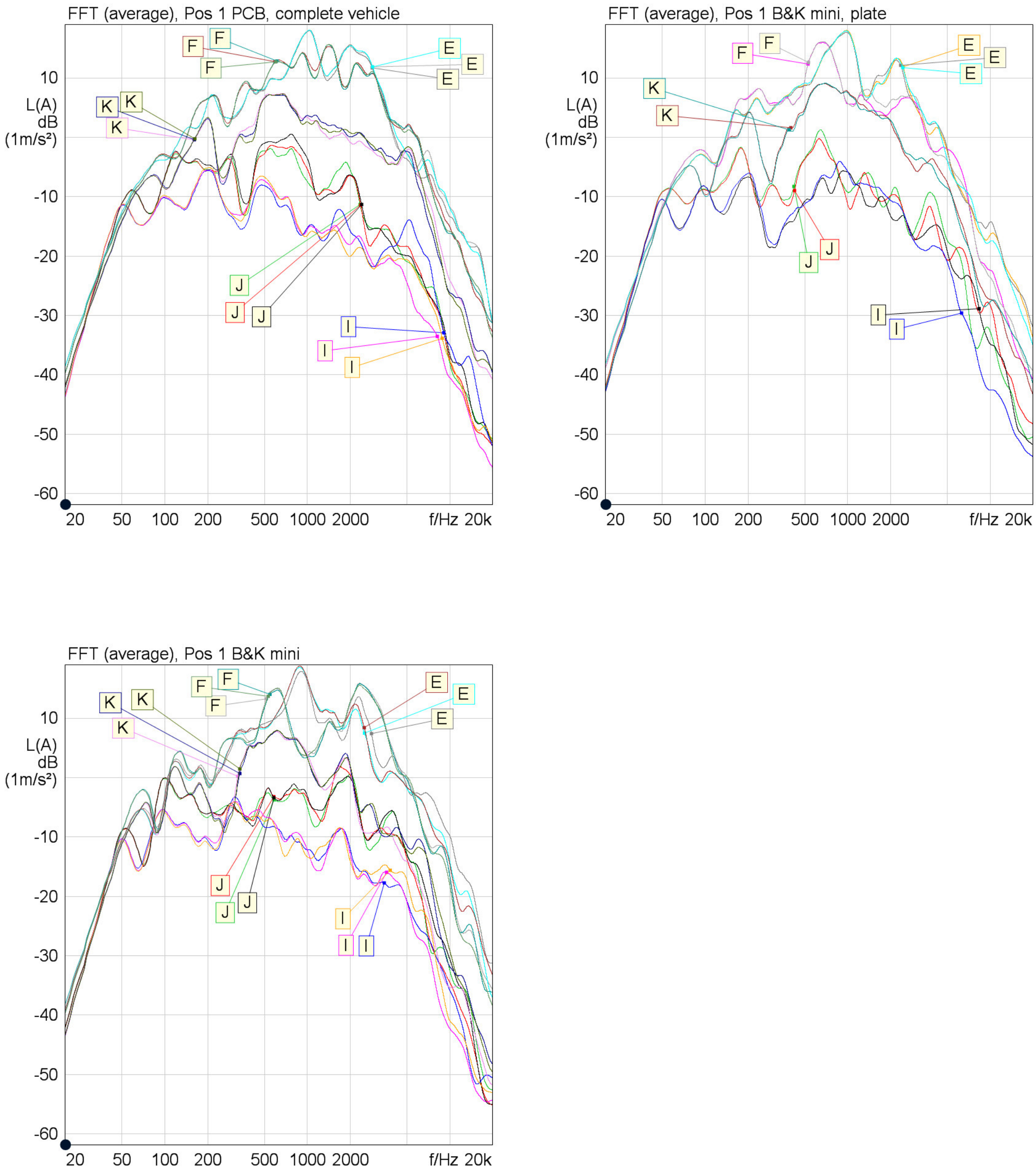


Fig. 6.10.: FFT analysis of the acceleration measurements of the samples E, F, K, I and J at position 1. Top left: complete vehicle, top right: handle mounted on the plate, bottom left: single handle.

7. Findings

As the measurements on the single handle provide satisfactory results, it is focussed on this solution to formulate a requirement, because it is easier to build up and it has really no other influence than the handle itself.

As it could be demonstrated in the previous chapter, the main, clearest and most reliable differences between samples of different perceived quality can be determined at measurement position 1. A handle snap back noise of good quality delivers a frequency response at this measurement point which does not show significant peaks in the frequency region of 50 to 5000 Hz, whereas a handle snap back noise of bad quality delivers a frequency response which consists of an increasing and decreasing part and shows one or more clear acceleration maxima between 500 and 4000 Hz.

That this finding applies generally, or for the here tested handle modifications, is shown in figure 7.1. All in this test rig (version B) measured samples can be seen in the graph on the top. To make it clearer, this figure is split below in the good and bad rated ones, whereby here the two medium rated samples are omitted. All these plots show that it can more or less clearly be distinguished between ″good″ or ″rather good″ and ″bad″ or ″rather bad″ by looking at the frequency response at that measurement point.

At this stage it is possible to introduce a recommended requirement level for the acceleration, which should not be exceeded in order to receive a handle snap back noise, which will be perceived as okay or better in the car. This requirement curve is presented in figure 7.2. In the figure on the left the four samples which were rated as the least sharp ones and the best in terms of quality are shown together with the recommended requirement curve. The graph on the right shows the requirement curve inserted in the plot with all samples. This makes clear again, that the focus should be put on reducing the acceleration mainly in the frequency range of 400 to 5000 Hz. (Side note: Sample B is the one with the original actual handle design at the date of the measurement. Sample E is the same but with removed rubber bump stops.)

The requirements that can be set for a handle snap back noise of satisfactory quality are thus based on an acceleration measurement on the point of the handle with the largest stroke. The acceleration at this point should not exceed the values that are graphically

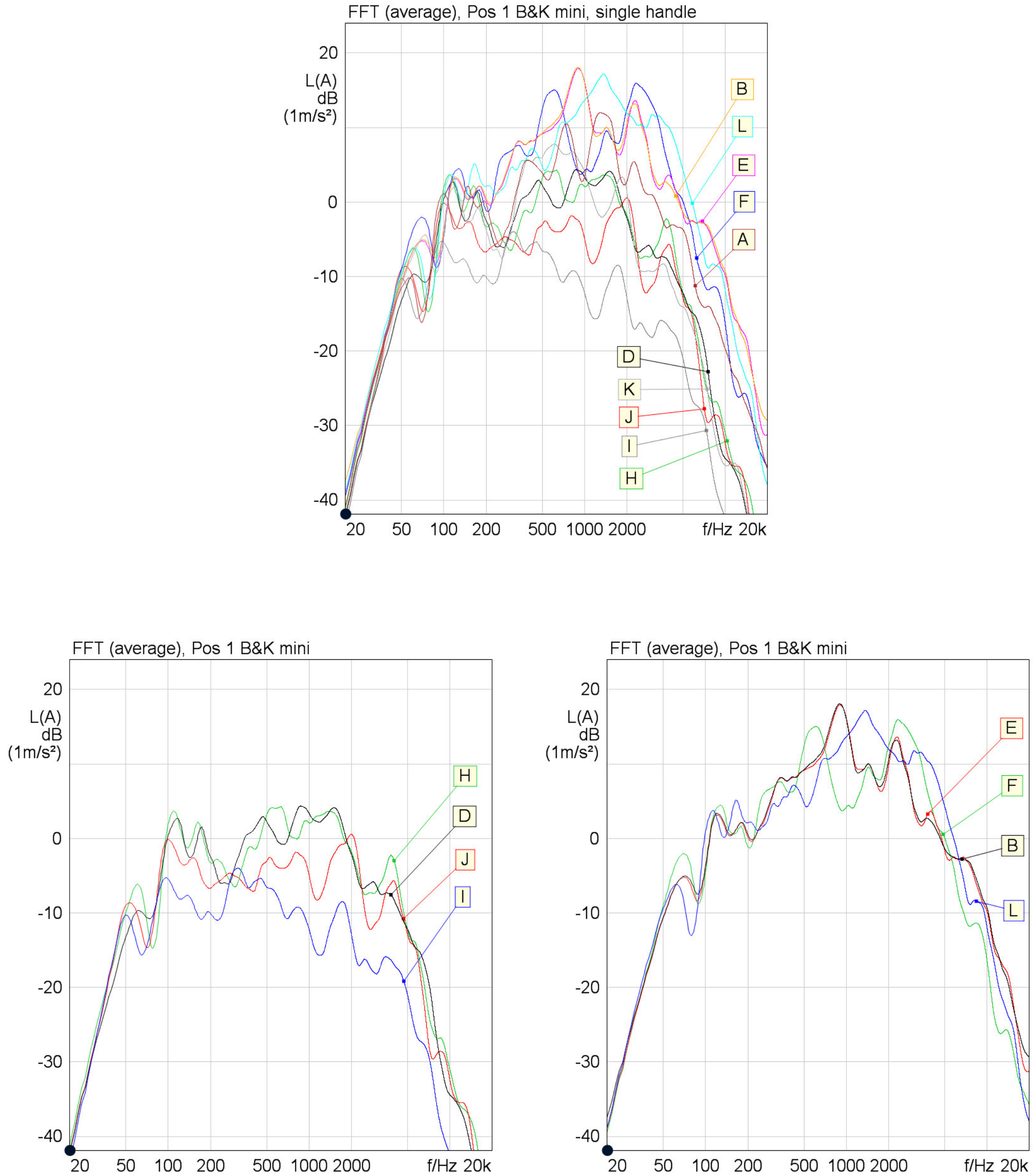


Fig. 7.1.: FFT analysis of the acceleration measurements on the single handle. Top: all samples, bottom left: four good rated samples, bottom right: four bad rated samples.

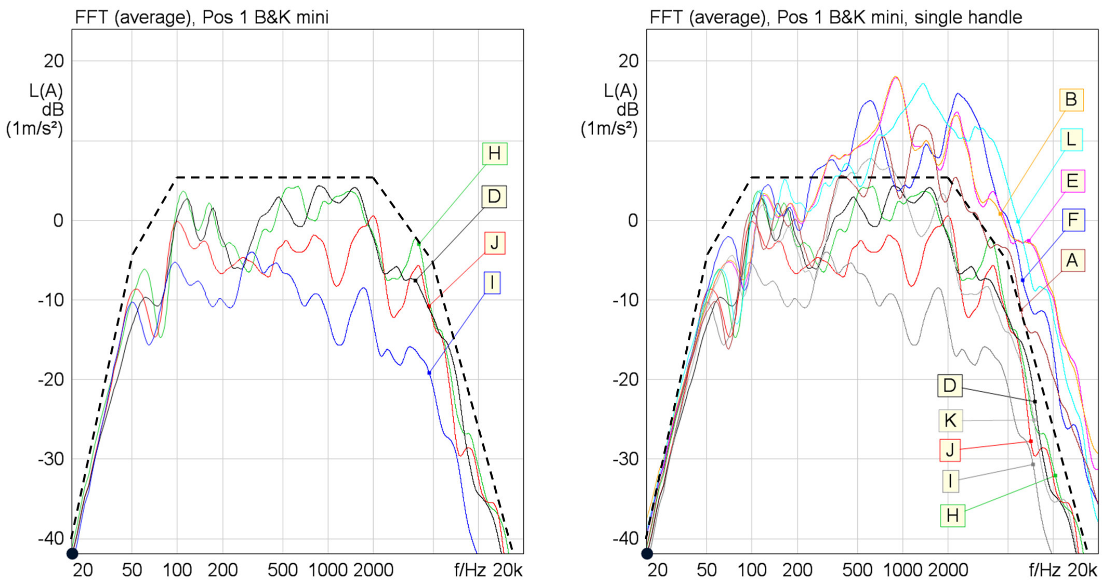


Fig. 7.2.: FFT analysis of the acceleration measurements on the single handle with the determined requirement curve. Left: four good rated samples, right: all samples, bottom right.

Frequency [Hz]	20	50	100	200	500
Level of acceleration [dBA (ref. 1 m/s^2)]	-40	-5	5	5	5
Frequency [Hz]	1000	2000	5000	10000	20000
Level of acceleration [dBA (ref. 1 m/s^2)]	5	5	-5	-25	-45

Table 7.1.: Recommended requirement curve in numbers.

presented in 7.2 and numerically in table 7.

8. Summary

This thesis work is about to develop a test rig which can be used to measure the sound of a handles snap back independently from the car door. The goal is to figure out if there is a measure that can be used to classify the quality of a handle snap back noise when performing a measurement on the handle only. The further goal is to quantify this measure and together with the instruction of the method formulate a requirement which can be used by designers and suppliers to pre-evaluate the sound quality performance of new designs or design changes. This procedure shall ensure in an early stage of development that the handle snap back sound will be perceived as a high quality sound by the customer when assembled to the door.

The first step of this development is to find a method how to generate a reproducible snap back event which is independent of variable influences. A rectangular piece of a plastic plate is used for that, whose one side dimension is exactly the measure of the full stroke of the handle. For the measurements this distance plate is clamped between the bracket and the pulled handle. A string is attached to this distance plate to be able to pull it out in order to let the handle snap back.

To get an idea of what is perceived as a high quality handle snap back sound, the gaskets and handles of the actual S60 handle design are modified in different ways in order to deliver a differently sounding snap back. Measurements are taken with all these modified handle versions with tree accelerometers, two attached on the handle, one attached on the door, and with an artificial head to record what a customer would hear when releasing the pulled handle. These recordings are then used in a listening test where the participants are asked to rate all the various snap back sounds in terms of particular attributes. The evaluation of this listening test provides a ranking which is the base for the assessment of the objective measurements.

Two versions of a possible test rig are built up to obtain objective measurements of the separated handles. One version is to mount the handle in a kind of door dummy which consists of a sheet metal plate of the thickness of the door panel and contains the original foot print cut outs to mount the handle in. Another suggestion is a setup with two metal sheets of the shape of the gaskets which are put between the bracket and the gasket of the handle as a place holder for the door panel. Both assemblies are fixed with rubber bands on the arm of a microphone stand. This provides a free suspension of the objects under test with minimized influence of the test rig on the measurements. The accelerometers are placed in the same positions as for the measurements on the complete vehicles.

The comparison of the results of the listening test with the acceleration measurements on the complete vehicle show that for the perception of quality the parameters loudness and sharpness are important. In terms of frequency response of the artificial head recordings the main difference between good and bad quality is determined in the frequency range of 1 -2 kHz. Bad quality assemblies show a rising part up to this frequency and a falling part for the higher region, whereas good quality assemblies do not show this maximum but rather a plateau shape with a more or less equal level in the region of 100 to 1000 Hz. Comparing these finding to the acceleration measurements a similar statement can be made. This is most obvious for the measurements of position 1. The acceleration level increases for bad quality samples and reaches its maximum at 1 to 2 kHz, while falling for higher frequencies. This does not count for the good quality samples.

A similar observation can be made when transferring the results of the evaluation of the acceleration measurement on the complete vehicle to the ones in the test rigs. For the ones with the plate as door dummy the bad quality handle assemblies deliver two acceleration maxima between 500 and 3000 Hz whereas the good quality ones do not show prominent maxima in this range. This performance can not be seen as clear for the other two measurement points. Also on the test rig solution B, which is the solution with small door place holders in gasket shape, the most significant differences in frequency response occur for measurement position 1. Bad rated samples show a significantly higher level of acceleration in the frequency range of 400 to 5000 Hz than good rated ones.

After this analysis it can be decided for test rig version B for several reasons. First it delivers good and meaningful results for acceleration at position 1. Furthermore this one is the cleanest and therefore preferable test rig design since it consists basically only of the handle construction itself and in comparison to the solution with the plate it has no other influences and also no other possible sources of error when it comes to producing it and building it up.

This knowledge allows to define a recommended requirement curve for the frequency range of 20 Hz to 20 kHz and to state, if the level of acceleration on measurement position 1 does not exceed the level of the recommended curve, the snap back sound of the handle will be perceived as ökayör better, when the handle will be mounted on the door of a car.

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A. Modifications of gaskets and handles

A.1. Gaskets

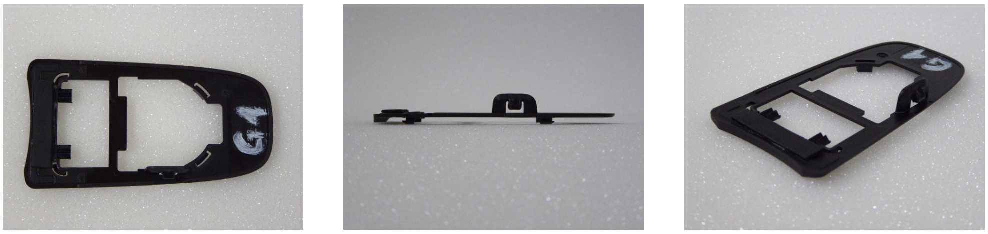

Fig. A.1.: Very thing rubber, 0.7 mm, whole width.

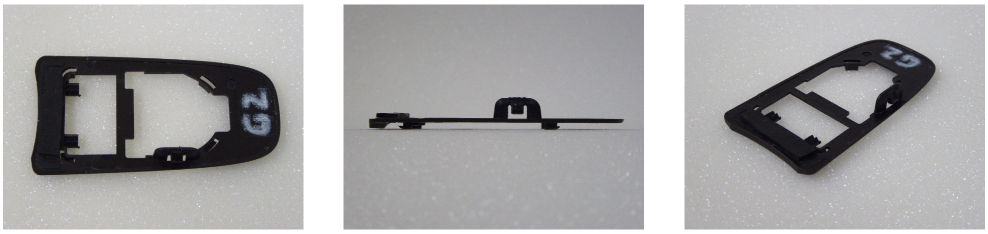

Fig. A.2.: Thin rubber, 1.5 mm, whole width.

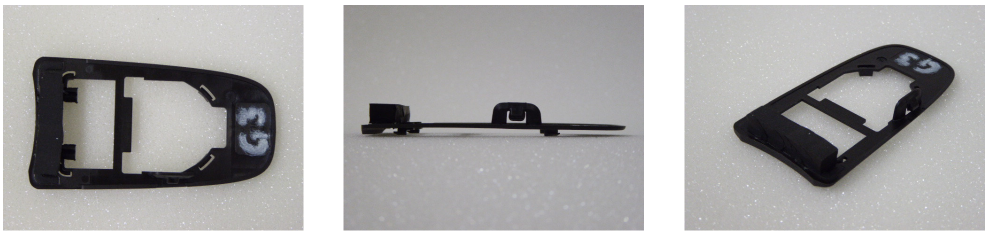

Fig. A.3.: Thick stiff rubber, 6 mm, whole width.

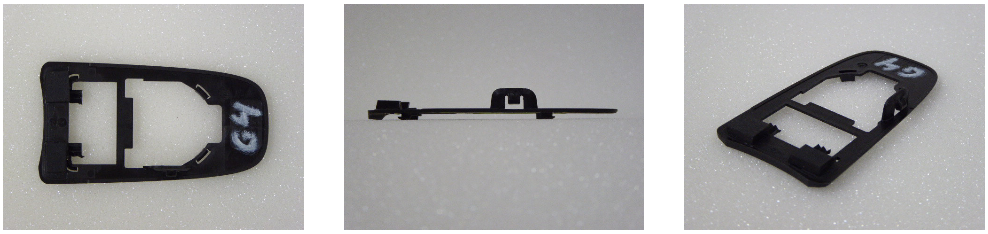

Fig. A.4.: Thin rubber, 1.5 mm, two squares.

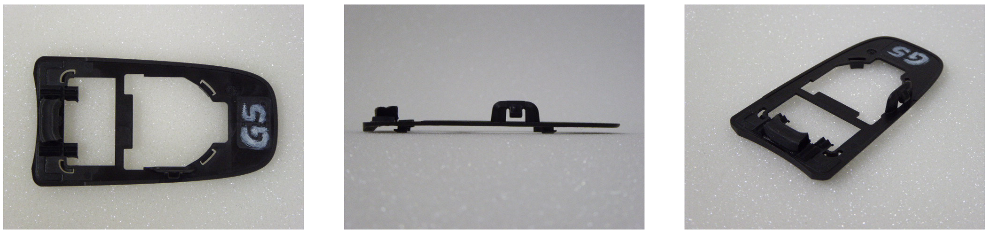

Fig. A.5.: Curved rubber, 4 mm, attached sideways.

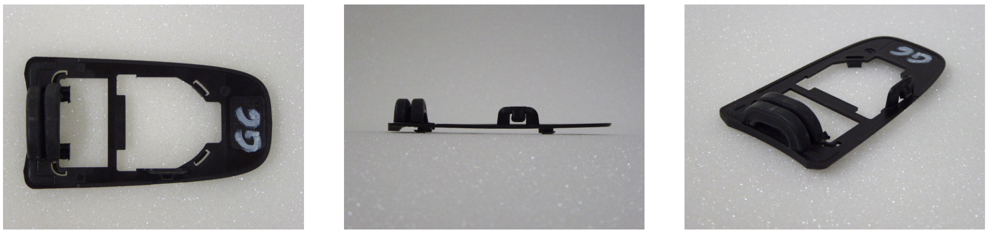

Fig. A.6.: Curved rubber, 9 mm, attached upright.

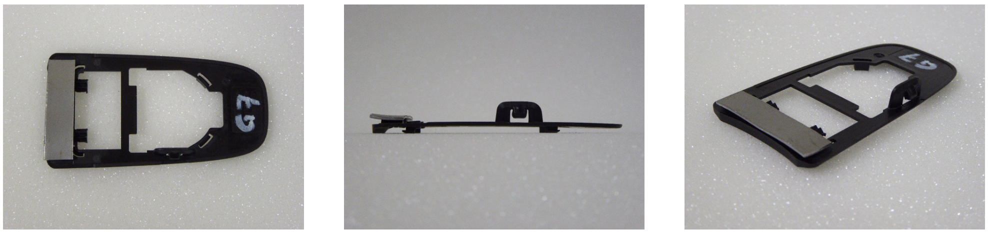

Fig. A.7.: Metal plate, 1 mm, attached on thin rubber, 1,5 mm.

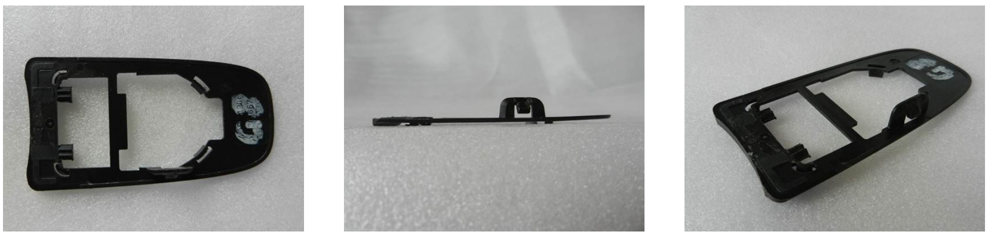

Fig. A.8.: Original, bump stops cut off.

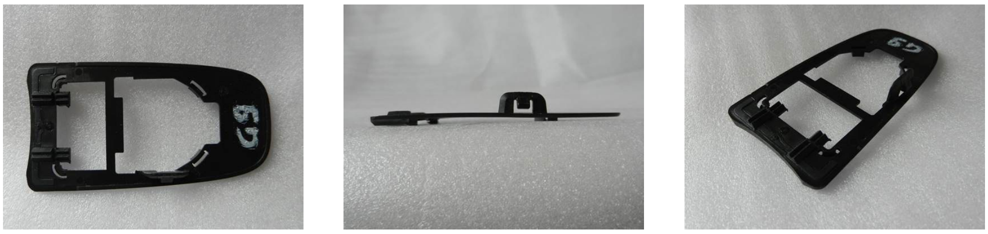

Fig. A.9.: Original.

A.2. Handles

Fig. A.10.: Standard handle, 70 g.

Fig. A.11.: Keyless handle, removed electrics, 70 g.

Fig. A.12.: Keyless handle, 110 g.

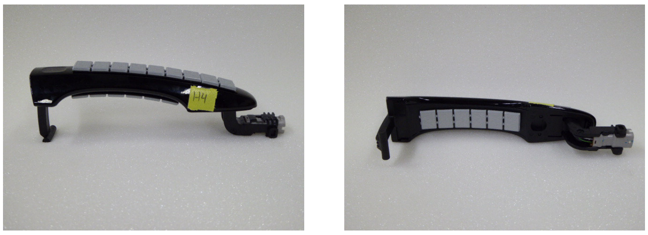

Fig. A.13.: Keyless handle with additional mass, 185 g.

B. Randomization list

A	H4 G9 passenger side
B	H3 G9 driver side
C	V70 passenger side STD version
D	H3 G3 passenger side
E	H3 G8 driver side
F	H2 G1 driver side
G	Audi driver side
H	H2 G5 passenger side
I	H4 G6 driver side
J	H2 G6 passenger side
K	H3 G3 driver side
L	H2 G8 passenger side

C. Answer sheet listening test

LISTENING TEST FOR EVALUATING OUTER DOOR HANDLE SNAP BACK SOUND

This study is conducted to evaluate the outer door handle snap back sound.

It consists of 2 parts. The first part is statistical information about yourself. It is ensured that this data will only be used for the statistical evaluation of this study and will not be related to your person. Nevertheless you are not forced to fill it in. Feel free to leave a field blank if you feel uncomfortable with the question.

Some general information about this test: You can drop off the test any time, without giving a reason for it. None of the answers can be right or wrong. Feel free to ask questions, if anything is unclear.

THANK YOU FOR PARTICIPATING!

Responsible:
Lisette Hey
Exjobbare NVH Components
VOLVO CAR CORPORATION
91650 NVH Center VCC
lisette.hey@volvocars.com

PART 1 – Personal information

What is your age? ___________

What is your gender? ☐ male ☐ female ☐ no specification

Do you have any hearing disorder? ☐ yes ☐ no

If yes, which kind? ____________________________________

Do you have experience with listening tests? ☐ yes ☐ no

Would you consider yourself as a trained listener? Yes ☐ - ☐ - ☐ - ☐ - ☐ No

Are you currently working at VCC NVH Center? ☐ yes ☐ no

PART 2 – Assessment of sound properties

You can listen to each sound by clicking on it. You can click and listen to each sound as often as you want. The sounds to be assessed are numbered from A to L.

Please assess each sound according to the following adjectives on a scale from 1 to 7.

Note: You can take a break to relax your ears and your perception whenever you like!

Imagine now, you are standing in front of your car and open the driver's door to enter (see also picture). You grab the handle, pull it back and let it snap back, when the door is open.

What do you think about the sound of the handle snap back?

Sound A

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound B

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound C

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound D

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound E

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound F

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound G

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound H

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound I

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound J

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound K

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Sound L

	1	2	3	4	5	6	7	
High quality								Low quality
Loud								Quiet
Sharp								Dull
Weak								Strong
Solid								Sounding/Ringing
Pleasant								Annoying
Suitable								Unsuitable

Here is room for your comments. What did you like/dislike about the test? Which question did you miss? Which other comments do you have on the sounds or on the listening test?

____
____
____
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THANK YOU FOR PARTICIPATING!

D. Ranking listening test

quality	loudness	sharpness	solidity	strength	suitability	pleasantness
high qu.	*quiet*	*dull*	*weak*	*pleasant*	*suitable*	*solid*
J	I	I	I	J	J	J
H	J	J	C	I	D	G
D	G	H	G	D	H	D
G	L	G	L	H	G	H
I	H	D	K	G	I	L
L	K	C	J	L	L	A
K	C	L	D	C	K	I
A	D	K	E	K	C	C
C	F	A	H	F	F	F
F	E	F	B	A	A	E
B	A	B	F	B	B	B
E	B	E	A	E	E	K
low qu.	*loud*	*sharp*	*strong*	*annoying*	*unsuitable*	*ringing*

Table D.1.: Rankings for all rated samples and all queried attributes.