CHALMERS

Influence of Vibration and Listening Environment on Perception of Recorded and BTPA Generated Interior Car Sounds

Master's Thesis in the Master's Programme in Sound and Vibration

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Abstract

The aim of this project is to get an understanding in what Binaural Transfer Path Analysis (BTPA) is in connection with the perceptual components for interior car sound. BTPA is an engineering tool for trouble shooting and sound design. The method describes the paths that the sound travels through a car body before coming into the interior of the vehicle. Normally the sound comes from the power train but it is also possible to include sound from wind noise.

The thesis could be divided into two parts:

- BTPA
- Stimuli/reality perception (Listening tests in listening room/SoundCar)

The results from the listening tests shows that sound quality and perception is very individual and can be perceived with both positive and negative reactions. Vibration has large affects on the sound, both positive and negative. It is very individual when a person starts to feel discomfort caused by vibration, and the differences between the individuals are large.

When comparing the sounds (Transient, idle, WOT) in both SoundCar/ listening room the sounds without vibration is perceived as:

- Having a higher amount of tonality
- Less powerful than the sounds with vibration
- Less unpleasant compared to the sounds with vibration (SoundCar)
- To some extent less rough in the SoundCar
- Less aggressive for transient and WOT sounds played in SoundCar and more aggressive for idle sounds played in the SoundCar
- In general less attention demanding (SoundCar)
- In general less reliable (SoundCar)

In general the listening test in the SoundCar is perceived as more real/ closer to reality compared to having the listening test in the listening room. The reality questions that were included in the test showed that there are slightly differences between sounds with vibration/without vibration. The feeling of being seated into a SoundCar with vibration is fairly convincing. If the result is expected to be closer to the reality the listening test should be performed in the SoundCar.

Keywords: BTPA, SoundCar, sound quality, listening test, sound and vibrations, psychoacoustics, perceptual components

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1 Introduction

1.1 Background

Binaural Transfer Path Analysis (BTPA) is a new method that is used today in the car industry. The BTPA method describes different paths that the sound travels through a car body and via the air before coming into the interior of the vehicle. Generally the sound comes from the power train but it is also possible to include sound from wind noise. The BTPA method was developed due to a lot of reasons, one important reason was the product-sound quality and troubleshooting, but the main reason in the beginning to develop the BTPA method was that there were several problems with the sound quality for vehicles, i.e. during acceleration. The method is both cost- and timesaving for the car companies. Compared to the precursor method, TPA, the time is reduced to the half compared with the BTPA method. Product-sound quality is perceived different among the individuals, i.e. a positive product-sound quality is noise that is perceived as good and gives a positive reaction on the individual while a negative product-sound quality makes the individual to feel uncomfortable. "Product-sound quality is a descriptor of the adequacy of the sound attached to a product" (Blauert & Jekosch 1997). In short terms the individuals have naturally cognitive and emotional effects on sound.

The great advantage with the BTPA method is that it is possible to listen binaurally to all sound paths that are measured in a BTPA measurement. In the beginning the artificial head were equipped with microphones in both ears during measurements with the BTPA method, but today a new method is under development, instead of microphones the artificial head can use loudspeakers. The artificial head is supposed to represent the averaged human of our population.

The BTPA method includes contributions from both airborne noise (≤ 8Khz) and structure-borne noise (≤ 2 kHz).

1.2 Aim/purpose

To understand what individuals think about sound that is perceived through a BTPA measurement/differences between listening room- SoundCar, two different listening tests are performed in this master thesis there one test will include sound from a BTPA measurement. The listening tests are performed at VOLVO PV Torslanda (VCC):

- SoundCar with/without vibration (SoundCar room, PV16)
- Listening room (3B52, PV)

After the listening tests different analysis are made on how the participants perceived the sound. The different sounds are not only coming from a BTPA measurement but as well from measurements performed outdoors. Ten samples in random order were played in the listening test in the SoundCar and eleven samples in random order were played in the listening room and the participant answered some questions about the sounds. Another aspect that is included in the listening tests is the aspect of reality.

The sounds that are used in the listening test are synthesized from a BTPA measurement and from separate measurements outdoors. The BTPA measurement will record all noise paths from the engine bay to the interior of the car and is performed on a VOLVO S80, I6. The sounds that are recorded outdoors include vibration. By using the BTPA method the individual sounds can be changed and tested on the participants. Interesting aspects are that one might see some perceptual difference while performing the test in a sound car/listening room. The thesis includes analyses of the different results.

The thesis could be divided into two parts:

- BTPA
- Stimuli/reality perception

In the first part one will get a perspective/understanding in what the BTPA method is, how it is performed and how it works. The second part includes both a BTPA measurement and listening tests.

Questions mentioned below that are answered by the listening test:

- Differences between the tests depending if they are performed in a sound car/listening room
- Comprehend of the realism/reality of the sounds
- Perceptual tonal components with/without vibration in different environments
- Differences between a BTPA measurement and a simulated BTPA measurement
- Differences in perception between the genders

A large literature study was spent to get information about what the BTPA method is and other interesting aspects about the method were investigated. Only few technical reports, technical articles were found and the content of the different reports/articles did not differ much. The report/ articles only gave a brief description about the method, not a detailed explanation as wanted. The only way to get a deeper understanding about the BTPA method was to participate in a BTPA measurement. Christer Svensson, supervisor at Noise- and vibration center, VOLVO PV Torslanda (VCC), has a great knowledge about the method. Christer Svensson has discussed and given excellent explanations about the BTPA method.

To understand the fundamental of method a lot of time was spent to understand what kind of transfer functions was important and how the BTPA method has developed in recent time. Today vehicle companies more commonly use the reciprocal measurements than the direct measurement (for further information look at chapter 2). To get an even better evaluation of the BTPA method NVH[1]-engineers has developed a SoundCar.

1.3 Performance

First a comprehensive literature study was performed to get an understanding in what the BTPA method is, how it works and how it is performed. All information was read through carefully and discussed with supervisors Christer Svensson, Noise- and vibration center, VOLVO Torslanda (VCC) and Anders Sköld, Chalmers. To understand how individuals' perceive sound a listening test was performed. The performances of the listening test were discussed with the supervisors Christer Svensson, Noise- and vibration center, VOLVO Torslanda, Anders Sköld Chalmers and Daniel Västfjäll, Chalmers.

[1] Noise, Vibration, Harshness

To get a greater knowledge about SQlab III and ArtemiS three measurements were performed at VOLVO PV Torslanda (VCC). The largest and most important measurement occurred week 44-46, the BTPA measurement was performed on a VOLVO, S80 I6 that occurred in the chassis dynamometer (CD1) and at the component room VOLVO PV Torslanda. In that test the BTPA method was accurate described.

In a general BTPA measurement one uses an artificial head. To get a connection between BTPA/perception of sounds, listening tests were performed with participants from VOLVO (VCC). The participants had different backgrounds; some with experience of sound other with less experience. The author tried to get participants from both the female- and male gender. The sounds included in the listening tests comes from a I6 powertrain:

- Sounds that comes from a BTPA measurement
- Sounds that are recorded by the author (with/without vibration)
- Some sounds from above are changed to see if the participant will react on the perceptual changed sound

After the listening test the results were analysed and evaluated with a statistical program called SPSS, different comparisons were made between the results from the participants.

1.4 Limitations

The individuals that participated in the test were people from VOLVO (VCC) that might have influenced on how the participants answered the questions. An employee at VOLVO (VCC) might think in other aspects on why the sound sounds like it does than a potential customer would do. The imperative listening test would be to use potential customers, but due to different reasons that was not possible.

During a listening test performed in a SoundCar car the participant is able to both hear the sound and to feel the vibration, but the question is how real the "feeling" is while looking to a "white wall". The reality is greater in a SoundCar than a listening room, but a large limitation with the listening test in the SoundCar was the view from the front seat. The feeling of driving a vehicle for real would be greater if one had used some kind of simulating tool that showed a "movie" every time the participant turned left/right or while the car accelerated. Another limitation with the sound car is that there are no possibilities to have more than one person inside if one wants to include vibrations.

The listening room has a limitation due to the size. To get a good listening test the participants should be as few as possible; one should avoid filling the room. Due to the limitation of time there are no possibilities to have less than five persons in the listening room.

The two listening tests are performed differently; depending on which group the participant belonged to. A limitation with the groups are that i.e. the listening test in the SoundCar must be divided into four days instead of having all during one day.

2 Theory

2.1 Binaural Transfer Path Analysis (BTPA)

Binaural Transfer Path Analysis is a method that describes the paths of sound in the interior of a vehicle; vibration is not included in the method. The sound can be measured at different positions of the vehicle, but the most common measurement takes place from the power train, that will spread the sound and the vibration into the interior of the vehicle. Tire and wind noise can also be included in the BTPA.

The BTPA method is developed by HEAD acoustics, Germany and it is a relative new method and widely used by several vehicle companies. The reason to develop this method was that the car industry had problems with the sound quality/vibration in some cars, and the problems were not known until late stages in the development time. To create a car with good sound quality the NVH engineers had to come in early in the development time, and the BTPA method made this possible.

There are big advantages to use the BTPA method, it is time saving and unwanted effect such as bad sound quality and vibrations in the interior of the vehicle, especially at the driver's position can be predicted before the vehicle is built [1]. It is very hard to predict the sound quality for an unknown chassis but the sound can be predicted through binaurally hearing and simulation with transfer path analysis of the sound. To make it as close to "reality" the simulation can include discrete vibrations and sound from the steering wheel and the seat, it is also possible using tire and wind noise. Before the BTPA method was developed NVH engineers used the TPA (Transfer Path Analysis) method. A comparison between BTPA and TPA shows that the time is reduced with more than half of the time if the BTPA method is used. The largest difference between TPA and BTPA is that in BTPA it is possible to get both time- and frequency domain. In a common TPA it is not possible to get the time data and without time data it is not possible to listen to the sound that travels through different part of the car body.

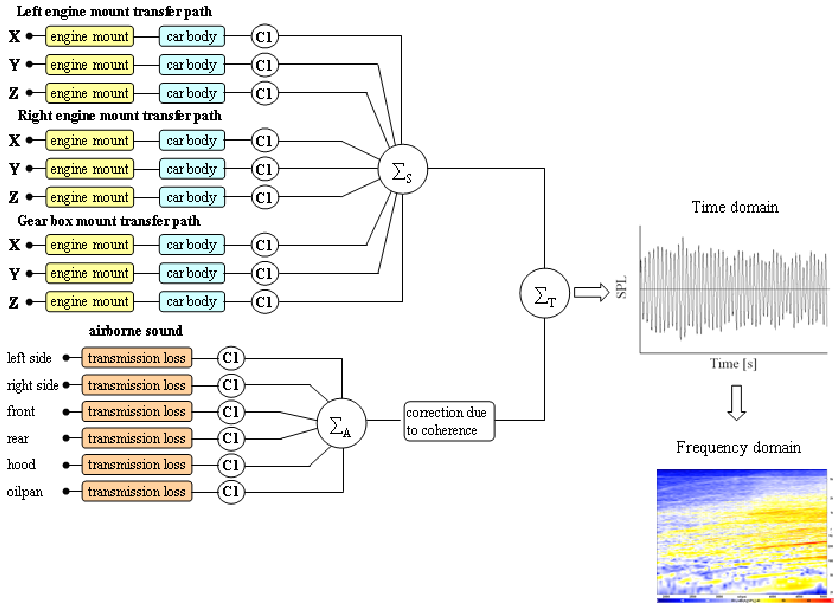


Figure 2.1 BTPA, airborne- and structure borne sound

The BTPA method is valid for airborne noise contributions to 8 kHz and structure-borne contributions to 2 kHz and it is important to separate the airborne noise and the structure-borne noise when using the method in the vehicle interior noise [2]. The BTPA method includes all transfer functions and is based on ArtemiS. In ArtemiS one can automatically combine all data, i.e. structure-borne sample, airborne sample, all samples summed together or maybe just one single combination; in conclusion the input data is combined automatically so that the wished output data is achieved. Each transfer path in the BTPA method will get a binaural sound sample as described above, and the samples are used during performing a listening test [2]. To optimize the feeling of "reality" for a participant in a listening test, using the BTPA method a sound car have been developed. Instead of being seated in a "test room" the participant will be seated in a car, and by that the listening test will feel more real. The sound car is equipped with discrete vibration, if wanted one can also include wind and tire noise. Usually these BTPA participants test is only performed at driver's position.

In conclusion the BTPA method makes it possible to shorten the vehicle time development and the vehicle interior sound can be known early for the NVH engineers and by that a good sound quality and vibration in the car can be achieved.

2.2 Interior noise

To understand the unwanted sound and the discrete vibrations in the vehicle all paths must be defined where the sound possibly can be transmitted and as well listen to how the sound will be in the interior of the vehicle through these specific paths. In the BTPA method one usually divides the measured paths in three coordinates, triaxial measurements. The triaxial (X, Y, Z) measurement could i.e. be performed both on the engine and the mount [3]. There are several paths that both the sound and vibration can be transported, and it is of great importance to find all paths.

Two transfer functions in the BTPA method are especially analysed:

- Structure-borne noise
- Airborne noise

To measure the transfer functions there are two methods available, reciprocal measurement and direct measurement. [6]

In the direct method a calibrated hammer is used at different positions at the vehicle that causes an excitation, and an artificial head is positioned at driver's seat. The artificial head has microphones positioned in both ears. For a reciprocal measurement a loudspeaker sends out an excitation signal that will be picked up by the acceleration measurement/sound pressure measurements and thereby analysed. [6] The largest difference between a reciprocal measurement and a direct measurement is that the artificial head has loudspeakers inside of the ears, instead of microphones. The loudspeakers makes the limitations less, it is possible to make measurements all over the body of the car that will make the reliability of the results greater.

To make it as real as possible the artificial head is used. It is of great importance to use this binaural technique so that result is close to what a human ear would perceive. Of course the ears of an artificial head are never the same as a human. The size of a human head, ears etc differs a lot among the population, but the artificial head should represent the average human.

Figure 2.2 Artificial head from HEAD Acoustics

In the BTPA method one can see which components of the vehicle that influence the sound quality negatively and positively by measuring the transfer paths from the source to the driver's ear. The structure-borne sound path can be determined through three transfer functions [4]:

- Mount damping
- Apparent mass
- ATF, Acoustic Transfer Function

In detail one can describe the mount damping as the connection between the acceleration at the body (a_{body}) and the acceleration at the engine (a_{engine}). The connection for the apparent mass is the force (a_{body}) that is exposed to the body (F_{body}) and the acceleration (a_{body}) that occurs at the body. The acoustic transfer function describes how the sound pressure in the vehicle interior (SPL) is connected to the force (F_{body}) that is exposed to the body.

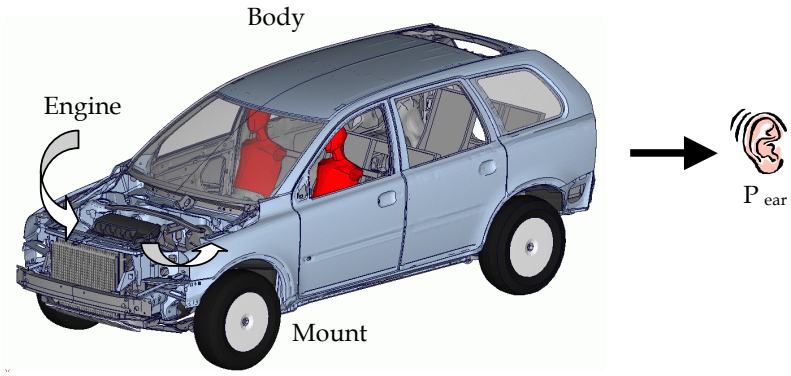


Figure 2.3 Schematic picture of structure-borne noise

The airborne sound path is determined through one transfer function [4]:

- Sound pressure level

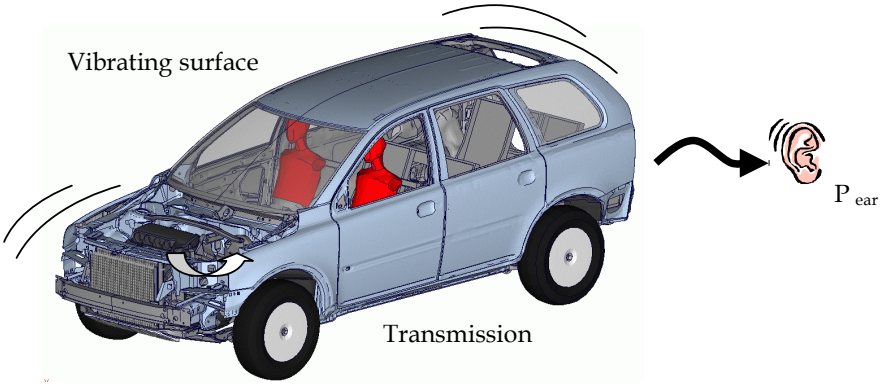


Figure 2.4 Schematic picture of airborne noise

The sound pressure level is measured at the driver's ear (SPL) and at the powertrain (SPL_e). In a mathematical point of view (simplified equation) the sound pressure level for the structure borne case can be described as (1) [5]:

$$a_{engine} \cdot \frac{a_{body}}{a_{engine}} \cdot \frac{F_{body}}{a_{body}} \cdot \frac{SPL}{F_{body}} \Rightarrow SPL \quad (1)$$

2.3 SoundCar

The perception of individuals is hard to define because of a lot of reasons, but the most important perspective is that individuals perceive sound differently. To make a good sound/acoustic quality in the interior of the vehicle different methods/tools can be used, i.e. BTPA. NVH engineers went a step further and created a virtual sound car that can be combined with the BTPA method.

The idea behind the SoundCar is that the participant should feel that it is nearer to "reality". For every move or action that the participant is doing she/he will get a response [2]. The SoundCar is equipped with vibration on both the seat and steering wheel. A lot of work and considerations are put on to create a good virtual environment in the interior of the car. Some aspects that are important:

- What kind of engine,
- Different speeds
- Background noise
- Tire and wind noise
- Etc.

Figure 2.5 The SoundCar at VCC

Each sound in the car is binaural, and the reason for that is to make sensation for the participant as real as possible. During the test the participant is using headphones (no cross talk will occur) [2]. It is not a requirement to use headphones, some tests uses loudspeakers, everything depends on what one wants to perceive with the test. The SoundCar is placed in a semi-anechoic chamber. The greatest advantage with using both BTPA and the SoundCar is that both sound and vibration is included in the test.

2.4 Standards about Noise and vibration quality for the interior noise [7]

Today there are no specific standards on how the interior noise should sound or how high the level should be; different vehicle companies have developed individual standards. The standard level for interior noise developed at VOLVO is similar to some extent to what some car magazines have written. The levels might be the same, but the measure procedure could differ. At VOLVO there are some conditions that should be fulfilled to get an acceptable interior noise when performing the measurements*:(SPL at different speeds Objective measurements according to standards)*

- Wind velocity max 3 m/s
- Highest gear used for manual/semi-manual
- D-position for automatic manual
- Acceleration max 0,5 m/s^2 during evaluation
- Level measured in dB (A), every second in the frequency region 20-20 000 Hz
- Level measured in dB (A) every tenth between 50 km/h-200 km/h[2]

[2] This requirement should be used if not measuring every second in the frequency region 20-20 000 Hz

Despite the conditions there are two requirements that should be fulfilled. It is mostly desirable to avoid peaks and fluctuations. At a speed change of 10 km/h the level should not change with more than 4 dB (A).

Special conditions/requirements for VOLVO is that a specific test code is used and a jury should approve a specific balance between noise sources and the noise quality. The result that will come out is a tenth gradation scale, which is called "Scale for subjective assessment". The goal is to achieve at least a good noise quality (7 in the scale).

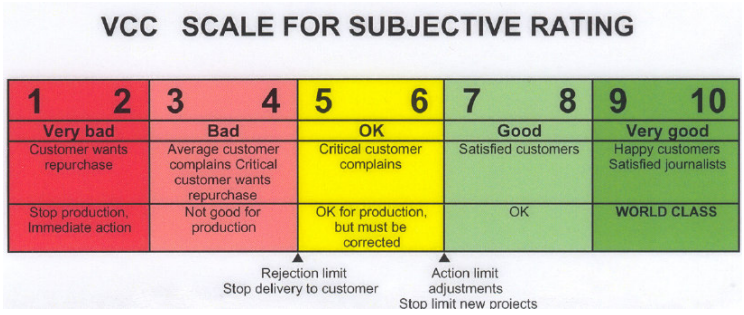


Figure 2.6 "Scale for subjective assessment"

2.5 Vibration affects on humans [8]

The discomfort for seated persons is increased when the magnitude of the vibration is increased. Through different experiments it is shown that differences between frequencies of vibration is small like differences between subjective persons. The vibration magnitude tells how powerful vibration is. It is in interest to know if the increase of the vibration magnitude is similar across the:

- Positions
- Axes
- Frequencies
- Durations
- Wide range of vibration magnitude

The human body has an increased sensitivity in the frequency region 4-6 Hz at high magnitudes. At high frequencies small changes can decrease the vibration transmission to the body, while at low frequencies the changes is less. The human body has non-linear ties in the dynamic response and the body is getting softer when the magnitudes of vibration increase. To reduce the resonance frequency the human body become non-linear while the vibration magnitude from the seats gets higher. Conclusion of this is that the body is trying to reduce the sensitivity to low frequencies with an increasing vibration magnitude.

The discomfort for a seated person mostly depends on the vibration of frequency. If the magnitude is constant the vibration frequency will not be equally discomfort on all frequencies, it will vary through the vibration frequencies. Depending on the body orientation and the vibration direction, low frequencies (below 1-2 Hz) will have the same movement transmitted trough the body, because the force that is acting on the body is proportional to the input acceleration.

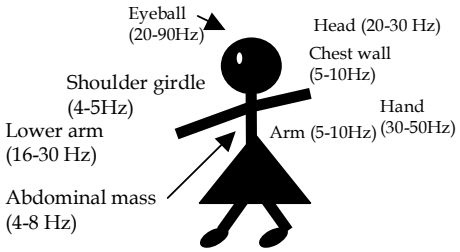


Figure 2.7 Resonance frequencies at different parts of the body [9]

At higher frequencies there will be an "overall" discomfort because the human body have various resonance frequencies at different parts of the body (i.e. the resonance frequency for the head is 20-30 Hz, for a eyeball 20-90 Hz for a arm 5-10 Hz etc.).

If the frequency increases to very high values the body will try to reduce discomfort of the vibration by making the body vibrate closely like the vibration input. At low frequencies the body will act like a rigid system and will be proportional to the acceleration. The maximum response of the body will depend on if it is:

- One resonance (lateral seat motion)
- Several resonance (vertical seat motion)

In the vertical set motion the body acts more sensitive, and the sensitivity will be twice as high for high frequencies than for low frequencies.

It is very individual when a person starts to feel discomfort caused by vibration, and the differences between the individuals are quite large. The differences could depend on a lot of reasons, which are mentioned below:

- Orientation of axes
- Position
- Posture
- Body size
- Body dynamics
- Age (little effect)
- Gender (female more sensitive to vertical vibration)
- Experience (little effect)
- Expectations (important for absolute judgment)
- Every point above is of great importance when discussing affect that comes through vibrations.

The expectations are important because of the absolute judgment. It is not important that the individuals experience from vibration discomfort is high, because every individual have an own judgment of what discomfort is, discomfort is nothing that you learn, it is something you feel. The age of an individual play a little role; this variable can be compared to experience. It does not matter how old you are, the discomfort of the vibration occurs in every age. Maybe, older people are more sensitive to vibration than younger. The author's theory for that is once an individual have been exposed to a vibration for a long time, the body might react to be more sensitive. If the health is bad, or the individual is in another way injured the sensitivity will be higher, and the discomfort for vibration might increase. The personality of the individual is of great importance. If the individual is "searching"/wants to feel vibration discomfort, the individual will have vibration discomfort.

The orientation of the axes can cause vibration on different parts on the body, in one axe the individual will start to feel discomfort on one part of the body, maybe the resonance frequency is achieved on that part of the body and the individual will start to feel a large discomfort.

Female and males are not always having the same preferences of what discomfort is, usually females are more sensitive than males to vertical vibration. The body size and the body dynamics can also influence when the individual starts to feel discomfort.

The position of the individual when affected of vibration discomfort is very individual. Some individuals feel more discomfort when they are affected while sitting and others might feel more discomfort when standing.

3 Measurement

Two measurements were performed:

- Record sound from automatic transmission with an I6 engine
- BTPA measurement

The first measurement was to record sound from different drive cases from an automatic transmission vehicle with an I6 engine. Several measurements of recording sound were performed, but only a few were used in the listening test. For further information about the measurements look at APPENDIX B.

Before the measurements started the givers (accelerometers and microphones) were glued in various important positions to the vehicle.

When the measurements were ready the following step was to analyse the results. At first, sound from the BTPA measurement was meant to be included in the listening test, due to the time those particular BTPA measurement had to be excluded and old BTPA sound were used instead. The old BTPA sounds come from Christer Svensson, supervisor VOLVO (VCC).

3.1 Equipment

All equipment used during the measurements come from VOLVO PV Torslanda (VCC). The equipment mentioned/explained below was used when recording sound/ stimuli. Some of the equipment was used in the BTPA measurement as well.

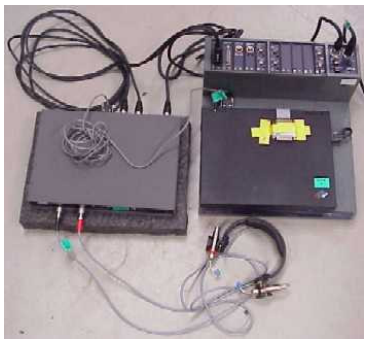


Figure 3.1 BHM IV, BEQ I, SQlab III

3.1.1 SQlab III [11]

SQlab III is a mobile multichannel tool that can be used for sound design, vibration investigations and acoustic analyses. SQlab III has 60 channels and two channels for RPM data. The channels can be configured with different modules such as microphone input, charge input

etc. SQlab III together with the artificial head makes it possible to make binaurally recordings and recordings of vibration by i.e. using accelerometers.

3.1.2 ArtemiS software [11]

ArtemiS software is an analyser tool for acoustics and vibrations and it can analyse several channels because it is a multichannel tool. It is easy to analyse noise/sound in ArtemiS and it is possible to listen to the sound that is recorded. The ArtemiS software can make modifications and documentations in both frequency and time domain for sound and vibration signals. The great advantage with the software is that it is very "wide", it has the possibilities to load with different modules, i.e. psychoacoustics, playback module, calculation module etc.

3.1.3 HMS III (Artificial head) [11]

The artificial head is an amazing tool that can measure sound with the same dynamic range as the humans. The artificial head has the ability to compromise the relevant acoustic components of the outer ear from a human. This means that what you record in one position with an artificial head is exactly what you will hear if you are seated at exactly the same position.

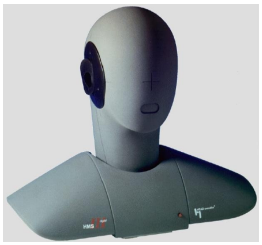


Figure 3.2 HMS III, Artificial head

The sound can be measured in several ways, i.e. with microphones. When measuring with microphones one must have in mind that two microphones in the ears cannot reproduce the sound in a correct way because of the influence that the head and the shoulder have on the sound have to be included as well. Both head and shoulder works as acoustic filters. All factors that might influence the sound field that reaches the inner ear are important, so that the human can localize the sound.

3.1.4 BHM IV (The binaural HEAD Microphone) [11]

When it is not possible to use an artificial head one uses a digital binaural measurement system to make the recordings of sound. BHM IV is a binaural head microphone and look like an ordinary headphone. Two small capsules placed at the end of the head microphone are conducting the sound via two small, highly sensitive electrostatic measurement microphones. The binaural head microphone are always coupled to a binaural equalizer, BEQ I, that does all the electronics for the sound measurement. The dynamic range for the binaural head microphone is comparable to the human hearing. Different modes of equalization can be chosen:

- Linear
- Independent-of-direction equalization
- Free-field equalization
- Diffuse-field equalization
- User-defined equalization (adaptable to ind. requirements)

Other equipment included in the measurement is shown in APPENDIX B.

3.2 BTPA measurement

The experiments included in the BTPA measurement were made at:

- Chassis dynamometer at VOLVO (CD1, semi-anechoic chamber), week 45
- Component room (semi-anechoic chamber) at VOLVO PV16, Week 45-46

The object that was used in the BTPA measurement was a S80 with an I6 engine. As mentioned before a BTPA is an engineering tool for trouble shooting and sound design. In this measurement 3-axial acc were placed at different positions to measure the transmissibility from the engine and the chassis mounts contribution from the structure borne sound. The transfer paths from the air borne sound are measured at the engine by the intake and exhaust system (each side at the engine). Each transfer path and its contribution to the sound can be calculated by multiplying the transfer functions with the input source signal. Every measurement point can contribute to sound into the interior of the vehicle.

All measurement at CD1 was made to get input data for the BTPA and to get the damping loss of the model. Microphones and 3-axial acc was placed around the engine to get as fine signal as possible to the model. There are several different ways to determine the structure borne path of the engine sound, and it is impossible to say which measurement method is correct. One way to measure could i.e. to divide the BTPA measurement into two parts:

1. Measure the subframe as a part of the body
2. Measure the subframe as a part of the engine

The measurements in CD1 (VCC) had different driving conditions simulated; there were three different loads (0% load, 50% load, 100% load) for both 3-gear and 4-gear.
The reason for doing measurements for different drive cases is that the engine works different depending of the gear. The sounds that radiates from the engine changes depending of which gear that is in use, the mounts work differently for different drive cases.

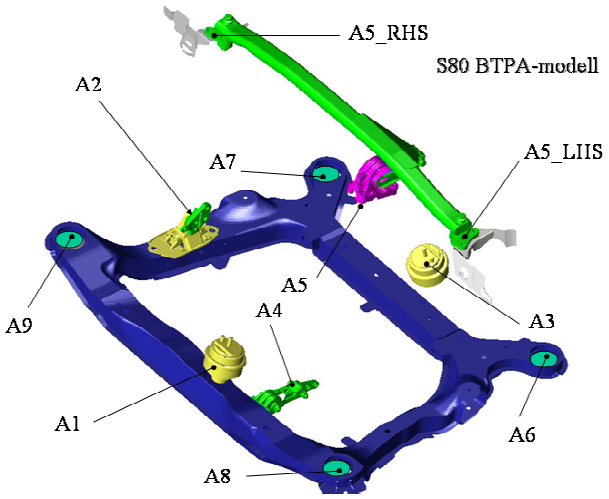


Figure 3.3 Schematic picture of the structure borne transfer paths from the body

In the component room different measurement were performed to measure the noise transfer function in the body of the car. Noise transfer function in this case is the same as body transfer function. Some coordinates to follow when measuring the noise transfer function is that the noise transfer function should preferably be below 55 dB/N.

When measuring a noise transfer function an impact hammer is used with three different tips:

- Steel
- Plastic
- Rubber

The reason for that is that i.e. the coherence will be better in the higher frequencies for a harder material, more energy is put into the higher frequencies. For better coherence in the low frequency region one should use rubber, because the rubber will put more energy in the low frequency region. A plastic tip on the hammer provides better coherence in the mid region frequencies.

In this specific noise transfer function measurement eight points were measured. At each point four knockings were made; by this means one can get a significant mean value. At all point one must knock in X-, Y-, Z-direction. The artificial head that is inside of the car is equipped wit a filter that only "hears" things above 22 Hz, anything below that value will be sorted away automatically. Interesting analyses for a noise transfer function is the coherence and the transfer function.

When the BTPA measurement is ready the first step afterwards is to analyse how well the simulated sound was correlated to the original sound. As one can see in figure 3.2 the sound patterns are quite similar. There are some differences between the measured and the simulated sound; i.e. the simulated sounds are slightly higher for frequencies around 300 Hz and around 500-1000 Hz.

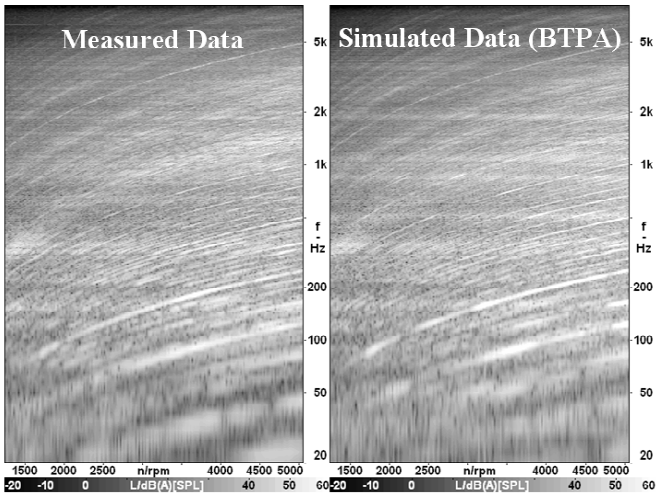


Figure 3.4 3-gear no load, measured vs. simulated sound

3.2.1 Equipment at chassis dynamometer

- 5 microphones (placed around the engine)
- 16, 3-axial acc
- Tachometer
- ArtemiS, SQlab III
- Cables
- Artificial head

3.2.2 Equipment at component room

- SQlab III
- Artemis
- Artificial head
- Impact hammer with steel, rubber and plastic tip
- 8, 3-axial acc placed at the body of the car

4 Listening test

A subjective listening test was performed with sounds from an I6 engine (S80, S40 and V70). Different types of sound were recorded and changed with help of vibration etc. The test was performed in that way that it was not possible to make comparisons between the groups. But even thou in some cases it has been possible to see differences between the groups. Two listening tests were made; both took place at VOLVO PV Torslanda (VCC). The listening tests were performed in a traditional listening room and in a SoundCar. The test occurred during a period of three weeks (week 47-49, 2004) at VOLVO Torslanda (VCC). By performing the listening tests the questions mentioned below can be answered:

- Differences between the tests depending if they are performed in a SoundCar/listening room
- Comprehend of the realism/reality of the sounds
- Perceptual tonal components with/without vibration in different environments
- Differences between a BTPA measurement and a simulated BTPA measurement
- Differences in perception between the genders

4.1 Participants

Totally 44 persons participated in the test. The participants are employees from different departments at VOLVO PV (VCC). About 25% of the participants were women. The total mean age of the participants was 39,4 years (male: 39,1 years, female: 40,3 years). Of all participants, 52,3% works at Noise- and Vibration center. Participants in the test did not get any economic compensation for participating in the test.

4.2 Performance

The participants were divided into two groups (group one and group two). One group started with the test in the listening room followed by the test in the SoundCar, while the other group started with the test in the SoundCar followed by the test in the listening room. The reason for doing this set up with the participants is to eliminate unwanted order effects. Another important aspect is to play different sequences of the sounds/ stimuli between the groups so they will not compare and of course be less bored of the sound. The sounds were analysed individually, after listening to the sound/ stimuli the participants filled the questionnaire. The participants were not allowed to look back and see what they had written before. Some participants found the sounds similar and wanted to look back to see what they had written/compare their answers. The listening formula can be divided into four parts[3]:

[3] APPENDIX C

1. Describing adjectives
2. What the participants thought about the sound
3. VCC scale for subjective rating
4. Reality questions

The first part consist of eight describing adjectives which had a scale between 0-8, i.e. if one uses the word rough, 0 meant not at all rough and 8 meant that it was very rough. The second part was a question about how the participant liked the sound. The scale in the second part was between –4 -4, where –4 meant that the participant do not like the sound at all, while 4 meant that the participant was very satisfied with the sound. The third part consists of a scale where the participant judged the sound with help of the VCC scale. In short term the VCC scale is asking for what the potential customer might think about the sound. The VCC scale is between 1-10, where 1 is very bad and 10 is very good. The fourth part is a page with reality questions. There are two questions about the reality in the listening test in the listening room and three questions about reality in the SoundCar. The first question was about how real/ similar to reality the situation was when listening to the sound. The scale for this question was between 0 and 100, where 0 meant that the sound is not at all like reality while 100 meant that it is exactly like the reality. The second reality question was about how present the participant felt in that specific situation, the scale for the second question is exactly the same as for the first question, 0 meant that the participant did not feel at all present an 100 meant that the participant felt totally present in the situation. Both the first and the second question are included in both the listening room and the SoundCar. The third question only occurs in the SoundCar. The third question is about how convincing the feeling actually is to be seated into a car, the scale for this question is between 0-10, where 0 meant that it is not at all convincing and 10 meant that it is very convincing.

In the listening test in the listening room eleven sounds were played, some similar to each other, other less similar. Four different types of sound were used[4]:

- WOT (3-gear, d-mode)
- BTPA sound (natural form, +2 dB, +4dB, +6dB)
- Idle (Idle, natural, idle sweep, idle bandstop order 95, idle –10dB order 93)
- Transient (natural form)

The sounds were changed differently as can be seen above. For the BTPA sound the structure borne sound were changed, +2dB, +4dB and +6dB. There were two different types WOT sounds, one of the sound were recorded with a S40, d-mode, while the other were recorded with a S80, 3-gear. The idling sound had some tonal components and to reduce the tonal components in the sound a filter was used to see if the perceptual reaction is different between the sounds. One idle sound was an idle sweep. The transient sound was recorded at Angeredsbron, Gothenburg, unfortunately during the recording of the transient sound it was raining, which was attempted to filter the rain.

The listening test in the SoundCar had 10 different stimuli/ sounds played:

- WOT (3-gear)
- Idle (natural form, idle –10dB order 93)
- Transient (natural form)

The SoundCar is constructed in that way that it is possible for tester to be seated in the car during the test. Sometimes the tester might even feel the vibration, even though that the front passenger seat is not equipped with vibration. The listening test in the SoundCar had three

[4] APPENDIX D

sounds that was included in the listening test in the listening room, WOT (3-gear), Idle and the transient sound. To see how vibration affects the perceptual reactions for the participant the vibration is changed (+5dB and
–5dB). The WOT sound is played with natural vibration, without vibration and with +5dB vibration. The idle sound is played in its natural form with vibration, without vibration and idle –10 dB order 93 with vibration. The transient sound is played with/without vibration and +5dB/ -5dB vibration. The different sounds are played in random orders in four different sequences, so that the participants wont be able to recognize the sound.

The test formulas were quite similar in the listening room and in the SoundCar. The main thing that was separating them apart was the questionnaire with the reality questions. In the listening room the participants got a questionnaire with reality questions at the end, after all sounds were played. In the SoundCar the participants got a questionnaire where the reality questions came after each sound.

To get a correct analysis the participant had to attend to both occasions (listening room and SoundCar). Before the tests started in the listening room the participants heard three different sounds to get an understanding on what kind of sounds that were involved. In the SoundCar the participants heard a city drive reordered by Head Acoustics, to get the feeling of how it feels to be seated in a SoundCar.

In the listening room there could be five persons at every test occasion, but in the SoundCar it was only possible to have one participant because it was only at the driver's position where vibration was included.

In the listening test the sounds could be played once/twice, depending if the participants wanted to hear it twice. It happened that the sounds were played several times because the participants wanted to hear it due to different reasons. I.e. the transient sound is very short, about 3 sec long, and that specific sound was played several times. In the SoundCar the sounds were played two times each, it happened that the participant wanted to hear a specific sound several times. Especially the transient sounds and the sounds without vibration. The total time for the listening test was about 20 min, and the total time for the test in the SoundCar was 30 min, of course the time varied between the participants.

5 Results

All data from the listening test were analysed statistically with the software SPSS 12.0. During the test several participants did not come to the second test, which led to that their results had to be excluded. In the beginning more than 50 persons announced their interest to participate in the listening test, and a high amount of the interested were women. In the end the author had 44 "valid"(participated in both occasions) participants. The listening tests were planned for 50 persons and it was possible to have a drop of 25-30 persons to get a statistically correct analysis.

The results can be divided into four groups:

- Listening room
- SoundCar
- Listening room vs. SoundCar
- Reality

In each group an analysis have been made for each part of the test. The first thing that is done is to make an ANOVA (analysis of variance) for every adjective etc. to see if there is a significant difference between the sounds/ stimuli in the four groups. The mean value is calculated and as well the comparisons/significance differences between each sound. The significant difference is 95%; this means that when making an investigation in SPSS the significant value most not exceed 5%, if it does exceed there will be no significant value, which means that one can not analyse the result. For each sound an analysis is made to see difference between the genders and the groups.

5.1 Listening room

In the listening room four different analyses are made between the sounds. Firstly an analysis is made between all sounds for each adjective/question. Secondly an analysis is made on the BTPA sounds for each adjective/ question. Thirdly an analysis is made on the idle sounds for each adjective/ question and the last analysis is to make a comparison between the WOT sounds in the listening room.

Analysis made in the listening room between all sounds:

1. Powerful
2. Unpleasant
3. Roughness
4. Attention demanding
5. Tonality
6. Aggressive
7. Desirable
8. Reliable

5.1.1 Analysis of all sounds

The first adjective, powerful has a significant difference between the sounds at 0,1%. There are no significant difference between the genders, but there are a significant difference between the groups (group one and group two) at 4,4%. In a pair wise comparison one can see that there are differences between these sounds (for further information about the sounds look at APPENDIX D).

There are not large differences between the groups but out of the graph (figure 5.1) one can see that group one, that started the test in the listening room has rated the sounds more positive than group two, that started with the test in the SoundCar.

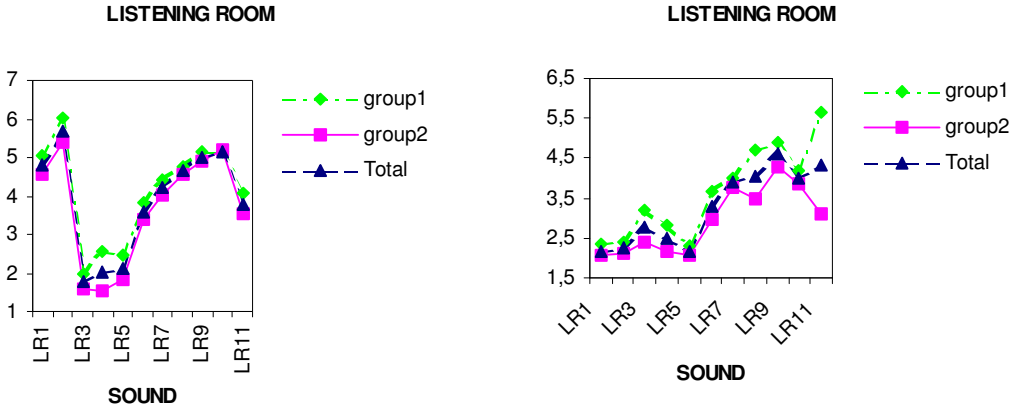
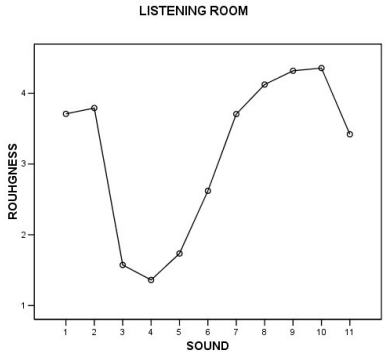


Figure 5.1 Powerful, all sounds, LR Unpleasant, all sounds, LR

The second adjective, unpleasant has a significant difference between the sounds at 0,01%. There is no significant difference between the genders but there is a significant difference between the groups at 3,6%. In a pair wise comparison one can see that there are differences between these sounds (for further information about the sound look at APPENDIX D).

Group one, that started the test in the listening room have rated the sounds as more unpleasant than group two that started with the test in the SoundCar (figure 5.1).

The third adjective, roughness has a significant difference at 0,1%. There are no significant differences between the genders or the groups.



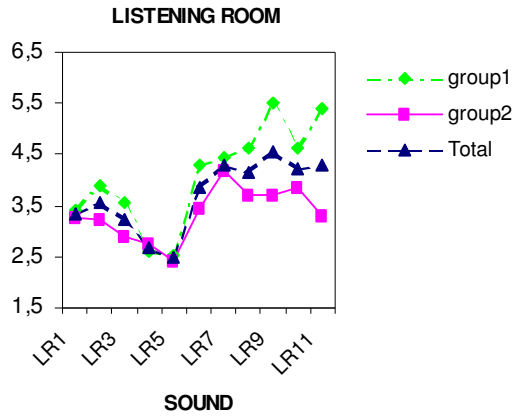
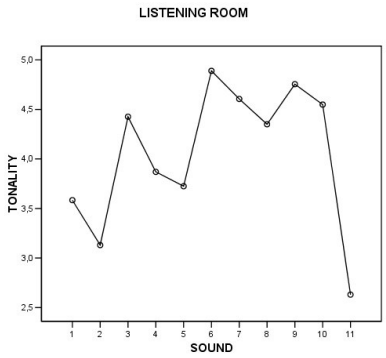


Figure 5.2 Roughness, all sounds, LR Attention demanding, all sounds, LR

The fourth adjective, attention demanding has a significant difference between the sounds at 0,01%. There is no significant difference between the genders but there is a significant difference between the groups at 1,9%. In a pair wise comparison there are differences between these sounds (for further information about the sound look at APPENDIX D). Group one that started with the test in the listening room has rated the sounds as more attention demanding than group two, that started with the test in the SoundCar (figure 5.2).

The fifth adjective, tonality has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between the sounds (for further information about the sound look at APPENDIX D).



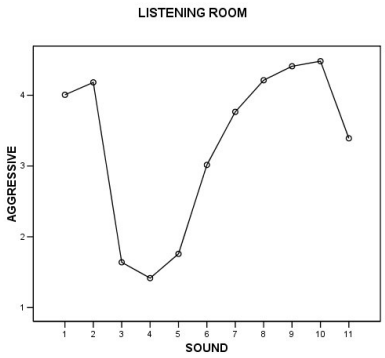


Figure 5.3 Tonality, all sounds, LR Aggressive, all sounds, LR

The sixth adjective, aggressive has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between the sounds (for further information about the sound look at APPENDIX D).

The seventh adjective, desirable has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between the sounds (for further information about the sound look at APPENDIX D).

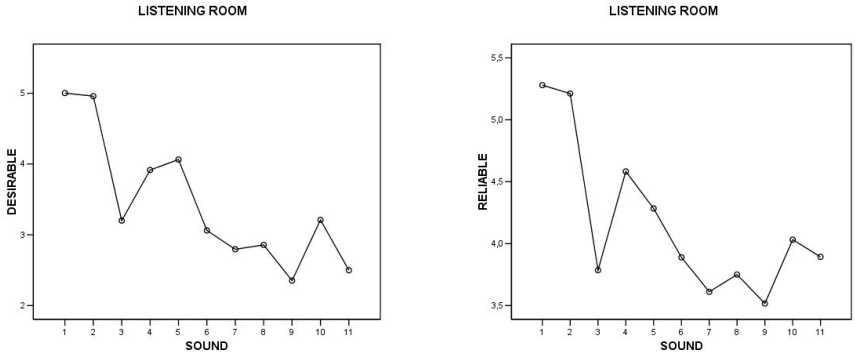


Figure 5.4 Desirable, all sounds, LR Reliable, all sounds, LR

The eight adjective, reliable has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between the sounds (for further information about the sound look at APPENDIX D).

In the second part of the test the participants were asked if they liked the sound, the data that was in the SPSS did not get a significant result to this question therefore no valid result/conclusion could be drawn.

The question to the participants where they should answer what they thought the potential customer would think about the sound has a significant difference at 0,1%. There are no significant differences between the genders or between the groups.

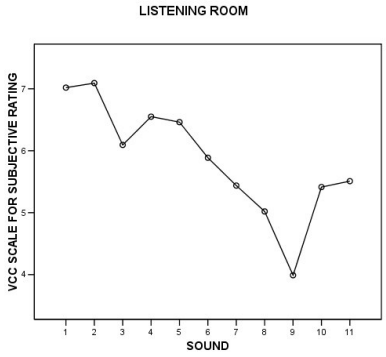


Figure 5.5 VCC scale for subjective rating, all sounds, LR

5.1.2 Analysis of the BTPA sounds

The second analysis made in the listening room was a comparison between the BTPA sounds. Four different BTPA sounds were included in the listening test:

1. Measured BTPA sound (LR1)
2. Simulated BTPA sound, structure borne sound +2dB (LR2)
3. Simulated BTPA sound, structure borne sound +6dB (LR3)
4. Simulated BTPA sound, structure borne sound +4dB (LR4)

The first adjective, powerful has a significant difference between the BTPA sounds at 0,1% (figure 5.6). The significant difference between the genders is 4,5% but there is no significant difference between the groups. In a pair wise comparison there is only a significant difference between the natural BTPA sound and the simulated BTPA sound that has +4dB in the structure borne sound. The females found the sounds in the listening room as more powerful than the males. The females rated the simulated BTPA sound, structure borne sound +4dB as the most powerful sound while the males rated the simulated BTPA sound, structure borne +6dB as the most powerful sound. The least powerful sound is in general considered to be the measured BTPA sound.

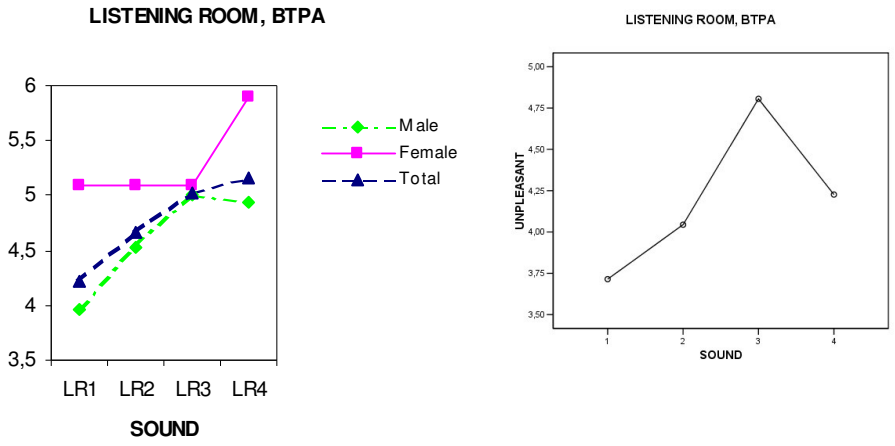


Figure 5.6 BTPA, powerful BTPA, unpleasant

The second adjective, unpleasant has a significant difference between the BTPA sounds at 0,01%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is only a significant difference between the natural BTPA sound and the simulated BTPA sound structure borne +6 dB. The most unpleasant sound is considered to be the simulated BTPA sound; structure borne +6dB while the least unpleasant sound is the measured BTPA sound (figure 5.6).

The third adjective, roughness has a significant difference between the BTPA sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is no significant difference for the adjective roughness between the natural BTPA sound and the simulated BTPA sounds. As expected the simulated BTPA sound, structure borne +6dB is rated as the roughest sound while the measured BTPA sound is rated as the least rough sound (figure 5.7).

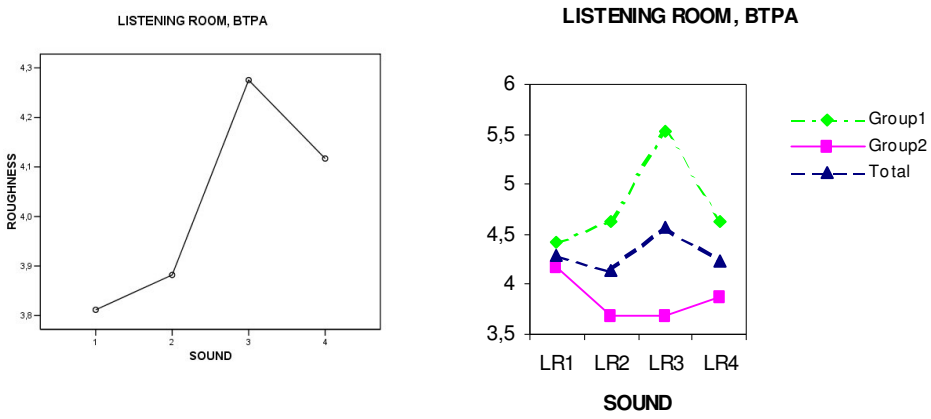


Figure 5.7 BTPA, roughness, LR BTPA, attention demanding, LR

The fourth adjective, attention demanding has a significant difference between the BTPA sound at 0,1%. There is no significant difference between the genders but there is a significant difference between the groups at 2,8%. In a pair wise comparison there is no significant difference for the adjective roughness between the natural BTPA sound and the simulated BTPA sounds. Group one that started with the test in the listening room has rated the BTPA sounds as more attention demanding than group two, that started with the test in the SoundCar (figure 5.7).

The fifth adjective, tonality has a significant difference between the BTPA sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is no significant differences for the adjective tonality between the natural BTPA sound and the simulated BTPA sounds. The simulated BTPA sound, structure borne +6dB is considered to have the highest amount of tonality while the simulated BTPA sound, structure borne +2dB has the lowest amount of tonality (figure 5.8).

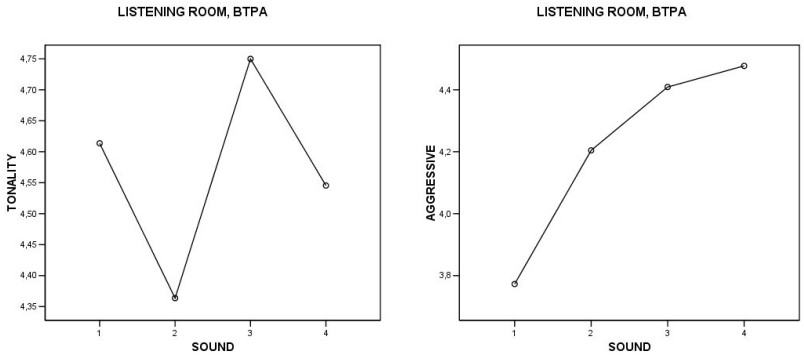


Figure 5.8 BTPA, tonality, LR BTPA, aggressive, LR

The sixth adjective, aggressive has a significant difference between the BTPA sounds at 0,1%. There are no significant differences between the genders or between the groups (figure 5.8). In a pair wise comparison there is a significant difference between the natural BTPA sound and the simulated BTPA sound structure borne +4dB. The BTPA sound, structure borne +4dB is rated as the most aggressive BTPA sound while the measured BTPA sound is rated as the least aggressive sound.

The seventh adjective, desirable has a significant difference between the BTPA sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference for the adjective desirable between the simulated BTPA sound, structure borne +4dB and the simulated BTPA sound structure borne +6dB. The simulated BTPA sound, structure borne +6dB is rated as the least desirable BTPA sound while the simulated BTPA sound, structure borne +4dB is rated as the most desirable sound (figure 5.9).

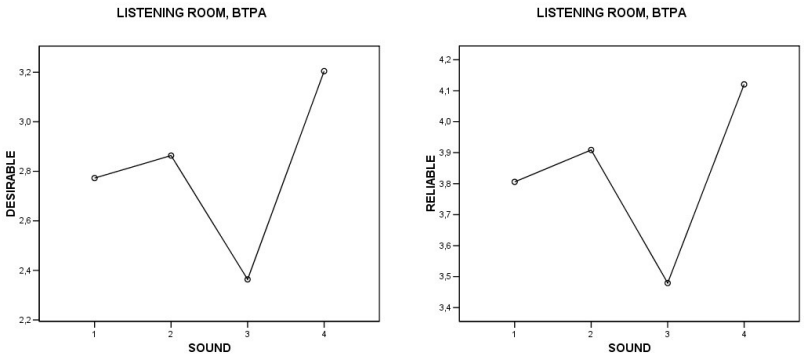


Figure 5.9 BTPA, desirable, LR BTPA, reliable LR

The eighth adjective, reliable has a significant difference between the BTPA sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference for the adjective reliable between the simulated BTPA sound, structure borne +4dB and the simulated BTPA sound structure +6dB. The simulated BTPA sound, structure borne +6dB is rated as the least reliable BTPA sound while the simulated BTPA sound, structure borne +4dB is rated as the most reliable sound (figure 5.9).

In the second part of the test the participants were asked if they liked the sound, and for that question there is a significant difference at 0,1%. The participants liked the simulated BTPA sound, structure borne +4dB the most while the simulated BTPA sound, structure borne +6dB is least liked (figure 5.10).

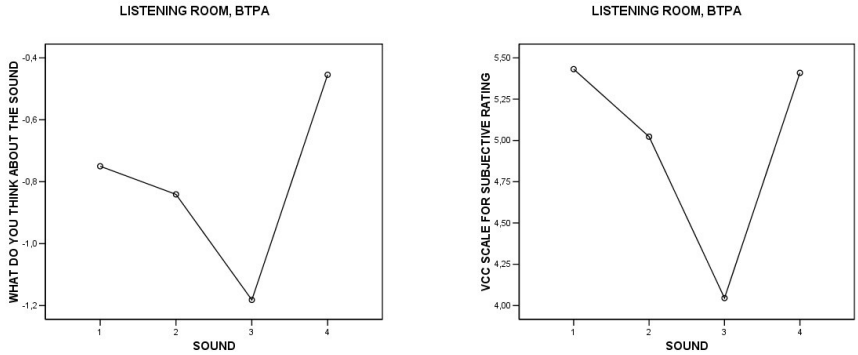


Figure 5.10 BTPA, What do you think about the sound, LR BTPA, VCC scale for subjective rating, LR

The question to the participants where they should answer on what they thought the potential customer would think about the sound has a significant difference at 0,1%. There are no significant differences between the genders or between groups. The potential customer would like the measured BTPA sound the most and the least liked sound for the potential customer is the simulated BTPA sound, structure borne +6dB (figure 5.10).

5.1.3 Analysis of the idle sounds

Third analysis in the listening room is to compare the idle sounds and see if there are differences between the sounds. The idle sounds included in the test:

1. Idle parking (LR1)
2. Idle parking -10dB, order 93 (LR2)
3. Idle parking bandstop, order 95 (LR3)

The first adjective, powerful has a significant difference between the idling sounds at 0,1%. There is no significant difference between the genders but there is a significant difference between the groups at 3,5%. In a pair wise comparison for the adjective powerful, there exist no significant difference between the idling sounds. Group one that started with the test in the listening room has rated the idle sounds as more powerful than group two that started the test in the listening room (figure 5.11). The largest difference between the groups is for the idle sound, -10dB, order 93, where group one rated the sound as the most powerful sound while group two rated the sound as the least powerful idle sound.

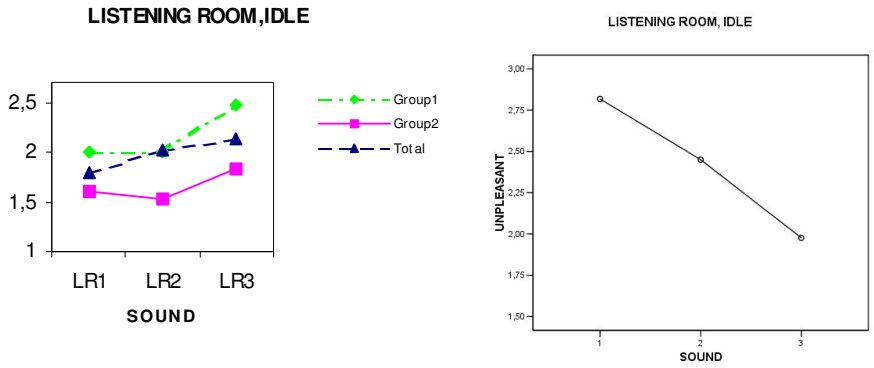


Figure 5.11 Idle, powerful, LR Idle, unpleasant LR

The second adjective, unpleasant has a significant difference between the idle sounds at 0,1%. There are no significant differences between the genders or the groups. In a pair wise comparison for the adjective unpleasant, there exist no significant difference between the idle sounds. In general, the most unpleasant sound is considered to be the natural idle sound while the idle sound with a bandstop filter, order 95 is considered to be the least unpleasant sound among the participants (figure 5.11).

The third adjective, roughness has a significant difference between the idle sounds at 0,1%. There is a significant difference between the genders at 3,7% but there is no significant difference between the groups. In a pair wise comparison for the adjective roughness, there exist no significant difference between the idling sounds. The females rated the idle sounds as less rough compared to the male participants. Both genders rated the idle sound changed -10dB, order 93, as the least rough sound. The roughest sound is considered differently between the genders, the females rated the idle sound, bandstop order 95 as the roughest idle sound while the males found the natural idle sound as the roughest idle sound (figure 5.12).

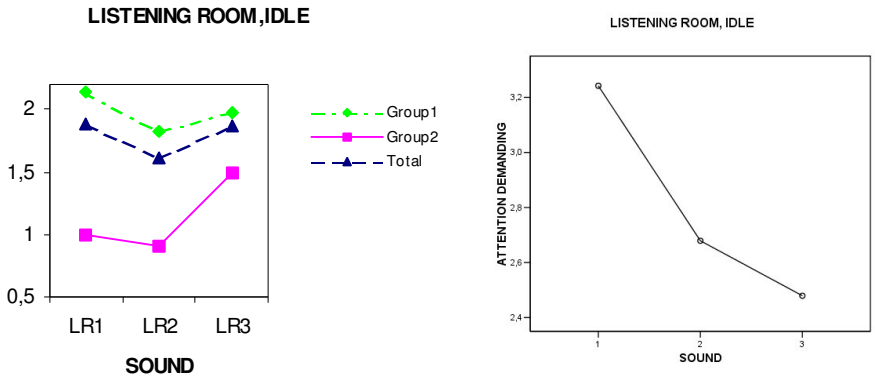


Figure 5.12 Idle, roughness, LR Idle, attention demanding, LR

The fourth adjective, attention demanding has a significant difference between the idle sounds at 0,1%. There are no significant differences between the genders or the groups. In a pair wise comparison for the adjective attention demanding there is a significant difference between the natural idling sound and the idling sound with a bandstop filter, order 95. The natural idle sound is rated, as the most attention demanding sound while the idle sound, bandstop order 95, is the least attention demanding sound (figure 5.12).

The fifth adjective, tonality has a significant difference between the idle sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference between the idle sounds:

- The natural idle sound and the idle sound, which is changed with -10dB, order 93
- The natural sound and idle parking with a bandstop filter, order 95.

The natural idle sound is considered to have the highest amount of tonality while the idle sound, bandstop order 95 is considered to have the lowest amount of tonality (figure 5.13).

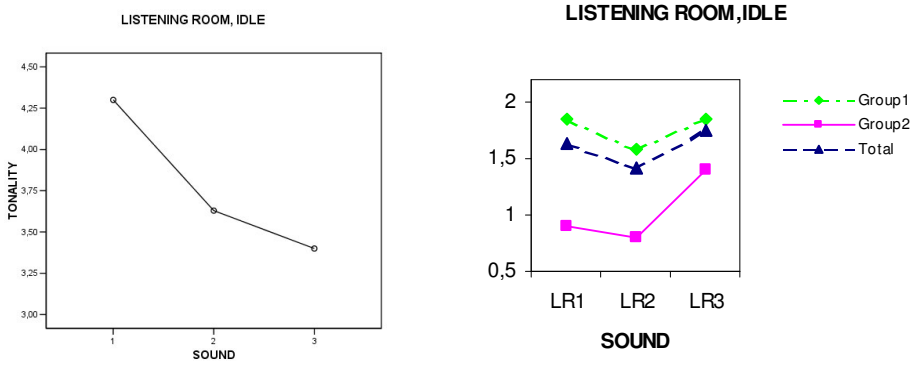


Figure 5.13 Idle, tonality, LR Idle, aggressive, LR

The sixth adjective, aggressive has a significant difference between the idle sounds at 0,1%. There is a significant difference between the genders at 4,4% and no significant difference between the groups. There are no significant differences in a pair wise comparison for the adjective aggressive. The males rated the idle sounds as more aggressive than the females. In general the most aggressive sound is considered to be the idle sound, bandstop order 95 while the least aggressive sound is considered to be the natural idle sound (figure 5.13).

The seventh adjective, desirable has a significant difference between the idle sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison one can see significant difference between the natural idle sound and the idle sound, which have a bandstop filter, order 95. The least desirable sound is the natural idle sound while the two other sounds are equally desired (figure 5.14).

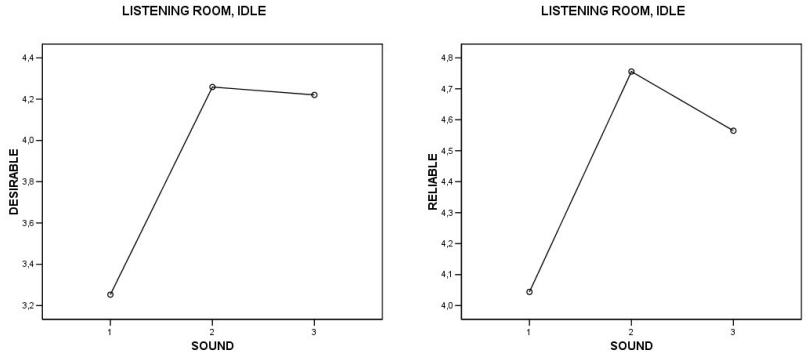


Figure 5.14 Idle, desirable LR Idle, reliable LR

The eight adjective, reliable has a significant difference between the idle sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison one can see differences between the natural idle sound and the idle sound, which is changed with a bandstop filter, order 95. The least reliable sound is considered to be the natural idle sound while the most reliable sound is considered to bet the idle sound, -10dB order93 (figure 5.14).

The question about how much the participants liked the sound did not have any significant difference; thereby no conclusions can be drawn.

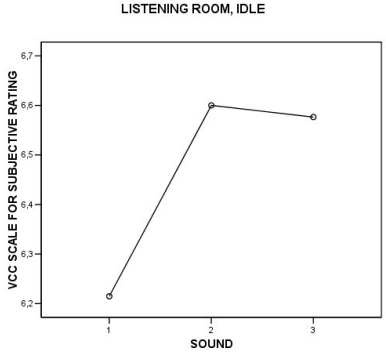


Figure 5.15 Idle, VCC, scale for subjective rating, LR

There is a significant difference at 0,1% for question where the participants should rate what the potential customer would think about the sound. There are no significant differences between the genders or between the groups. There are no significant differences in a pair wise comparison for the question. The difference between the ratings of the idling sounds is not large, but one can see that there is a minor difference for the filtered sounds. The potential customer liked the filtered idle sounds more (figure 5.15).

5.1.4 Analysis of the WOT sounds

The fourth and last analysis made in the listening room is between the WOT sounds. There were only two WOT sounds included, the first sound were recorded with a S40 (3rd-gear) and

the second sound were recorded with a S80 (d-mode), both with an I6 engine. The first eight adjectives[5] in the test showed a significant difference between the sounds at 0,1%. On the question about how they liked the sound there was a significant difference between the genders at 3,8% but there were no significant difference between the groups. There were no significant differences in a pair wise comparison. The male participants liked the WOT sounds slightly more than the female participants. On the question on what the potential customer would think about the sound there were a significant difference at 0,1%. Between the genders there were a significant difference at 1,6%, and there were no significant difference between the groups. The male participants rated the sounds higher for the potential customer compared to the female participants (figure 5.16).

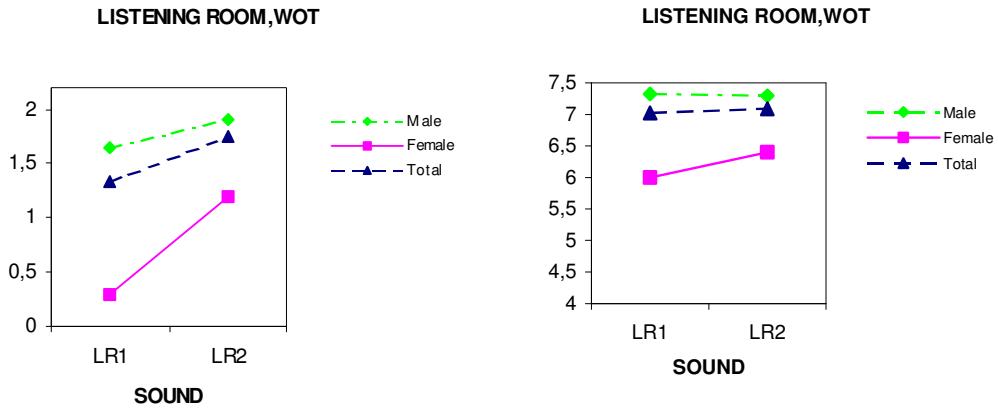


Figure 5.16 WOT, how much do you like the sound, LR VCC, scale for subjective rating, LR

5.2 SoundCar

The sound car is equipped with both sound and vibration; thereby an analysis where vibration is included can be made. The analysis in the SoundCar will be performed as previous analyses made in the listening room. Firstly eight describing adjectives will be analysed followed by two questions; the first question asks the participants about how much they liked the sound, the second questions asks what the potential customer would think about the sound. Four different analysis are made in the evaluation part of the SoundCar:

1. A comparison between all sounds
2. A comparison between the WOT sounds (natural, +5dB vibration, without vibration)
3. A comparison between the idle sounds (natural, without vibration, Idle parking vibration –10dB order 93)
4. A comparison between the transient sounds (natural, without vibration, +5dB vibration, -5dB vibration)

The first adjective, powerful has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.17). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

[5] APPENDIX D

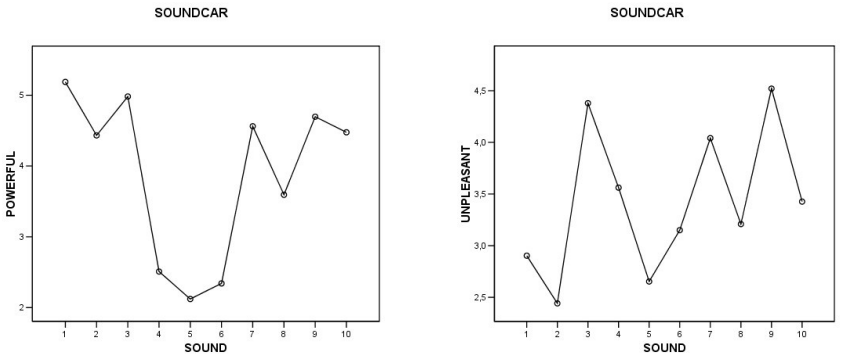


Figure 5.17 Powerful, all sounds, SC Unpleasant, all sounds, SC

The second adjective, unpleasant has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.17). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

The third adjective, roughness has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

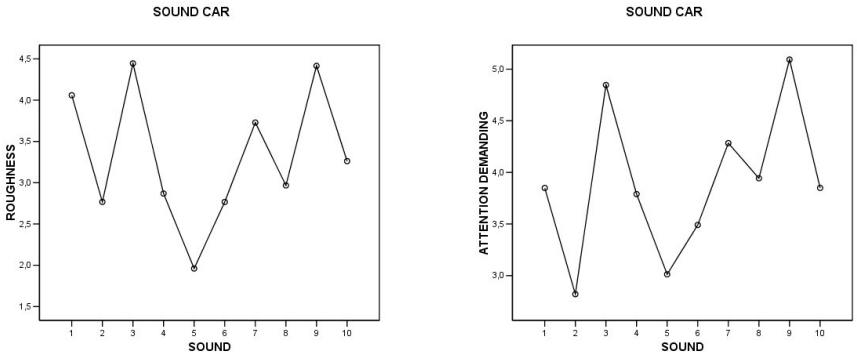


Figure 5.18 Roughness, all sounds, SC Attention demanding, all sounds, SC

The fourth adjective, attention demanding has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.18). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

The fifth adjective, tonality has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.19). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

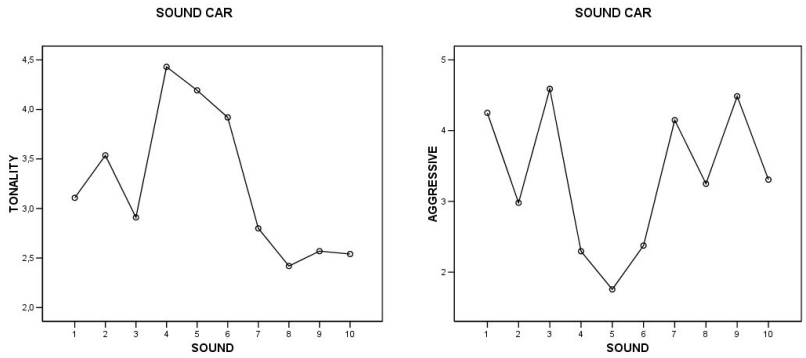


Figure 5.19 Tonality, SC Aggressive, all sounds, SC

The sixth adjective, aggressive has a significant difference between the sounds at 0,1 %. There are no significant differences between the genders or between the groups (figure 5.19). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

The seventh adjective, desirable has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.20). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

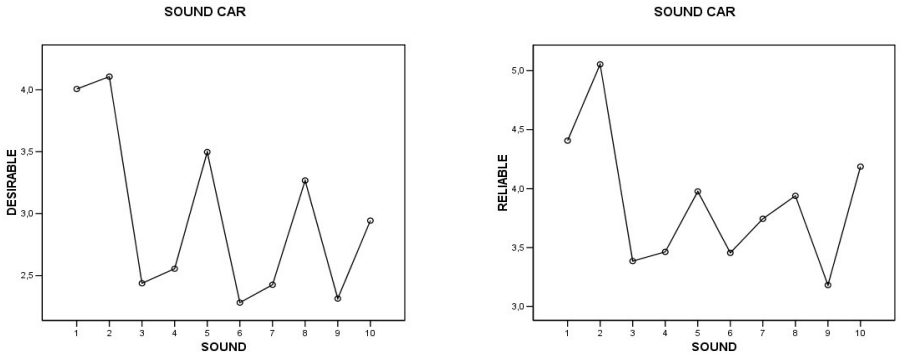
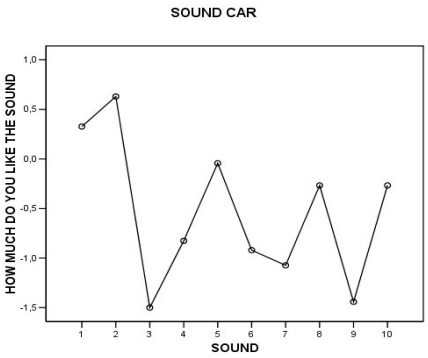


Figure 5.20 Desirable, all sounds SC Reliable, all sounds SC

The eighth adjective, reliable has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups (figure 5.20). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

The second part of the questionnaire asks how much the participant liked the sound. The question has a significant difference at 0,5%. There are no significant differences between the genders or between the groups (figure 5.21). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).



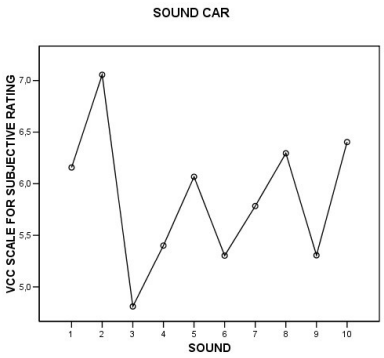


Figure 5.21 How much do you like the sound, all sounds SC VCC scale for subjective rating, all sounds SC

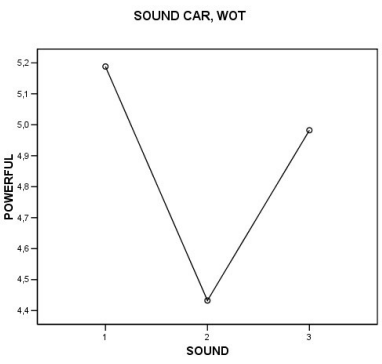
The third part of the questionnaire asks the participants what a potential customer would think about the sound. The significant difference between the sounds for the question is 0,1%. There are no significant differences between the genders or between the groups (figure 5.21). In a pair wise comparison between the sounds one can see that there are differences between the sounds (for further information about the sound look at APPENDIX D).

5.2.1 Analysis of the WOT sounds

The second analysis made in the SoundCar is between the three WOT sounds:

1. WOT, natural (SC1)
2. WOT, without vibration (SC2)
3. WOT, +5dB vibration (SC3)

The procedure for the analysis is the same as the previous analysis made in the listening room/SoundCar. Firstly the eight adjectives are analysed (first part of the questionnaire), followed by part two and three in the questionnaire. The first adjective, powerful has a significant difference between the sounds at 0,1 %. There are no significant differences between the genders or between the groups. In a pair wise comparison one can see that there are no significant differences between the sounds. The WOT sound with natural vibration is considered to be the most powerful WOT sound while the WOT sound without vibration is considered to be the least powerful WOT sound (figure 5.22). There is only a slight difference between the WOT sound with natural vibration and the WOT sound with +5dB vibration.



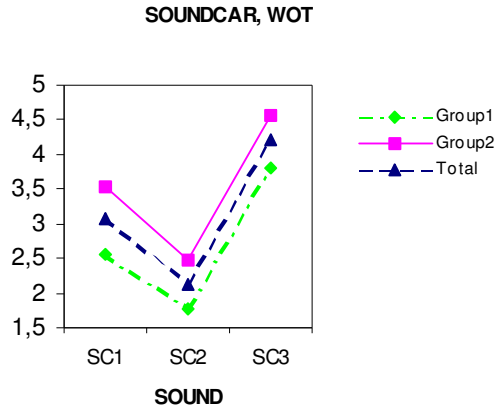


Figure 5.22 Powerful, WOT SC Unpleasant, WOT SC

The second adjective, unpleasant has a significant difference between the sounds at 0,1%. There is no significant difference between the genders, but there is a significant difference between the groups at 4,5%. In a pair wise comparison between the sounds there are significant differences between all three sounds. Group two that started the tests in the SoundCar has rated the sounds slightly higher than group one that started with the test in the listening room (figure 5.22). In general the most unpleasant sound is the WOT sound with +5dB vibration while the WOT sound without vibration is the least unpleasant sound.

The third adjective, roughness has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are significant differences between all sounds. As one can see in the figure 5.23 below the WOT sound without vibration is the sound with lowest amount of roughness, and the WOT sound with +5dB vibration is considered to have more roughness in the sound.

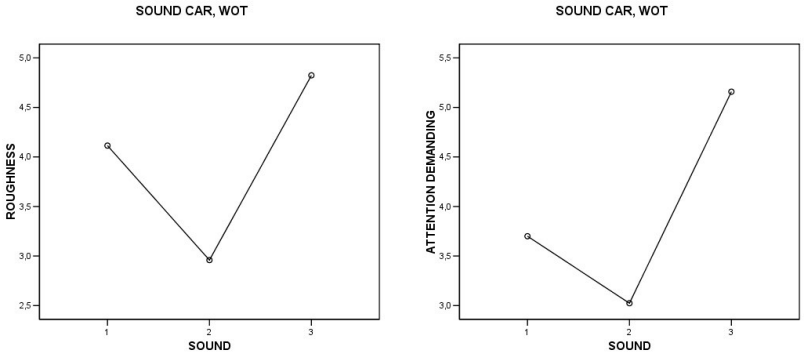


Figure 5.23 Roughness, WOT SC Attention demanding, WOT SC

The fourth adjective, attention demanding has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there are significant differences between all three sounds. In figure 5.23 one can see that the WOT sound with +5dB vibration is rated higher for being attention demanding than the WOT sound without vibration.

The fifth adjective, tonality has a significant difference at 0,1%. There are a significant difference between the genders at 1,6% and a significant difference between the groups at 5%. The males rated the tonality slightly lower than the females. Group two that started the tests in the SoundCar rated the tonality in the sounds higher than group one that started the test in the listening room (figure 5.24). In general the sounds without vibration is considered to have a higher tonality than the sounds with vibration.

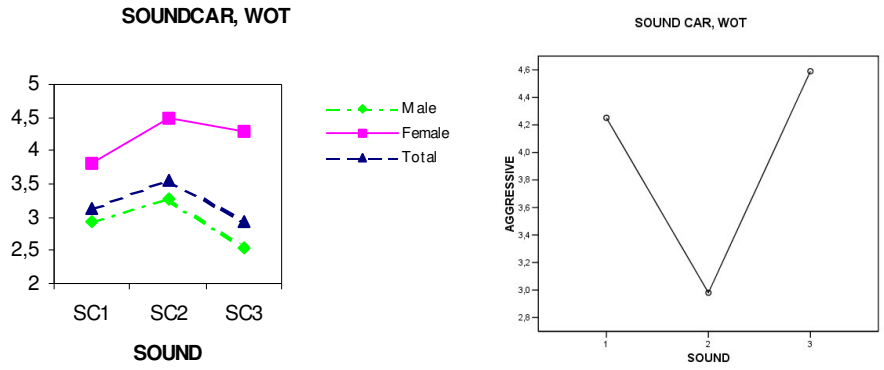


Figure 5.24 Tonality, gender WOT SC Aggressive, WOT SC

The sixth adjective, aggressive has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there are significant differences between the natural WOT sound with the WOT sound without vibration and the WOT sound with +5dB vibration with WOT without vibration. The WOT sound without vibration is considered as the slightest aggressive, and the WOT sound with +5dB vibration is considered as the most aggressive (figure 5.24).

The seventh adjective, desirable has a significant difference between the sound at 0,1%. There is a significant difference between the groups at 1,7% but no significant difference between the genders. In a pair wise comparison there is a significant difference between the natural WOT sound and the WOT sound +5dB vibration and with the WOT +5dB vibration with both WOT natural and the WOT without vibration. Group one, that started with the listening test in the listening room are slightly more positive to the sounds than group two that started with the listening test in the SoundCar (figure 5.25). In general one can say that the WOT sound without vibration is the sound that is the most desirable compared with the other WOT sounds in both groups. The WOT sound with +5dB vibration is the sound that is least wanted in both groups.

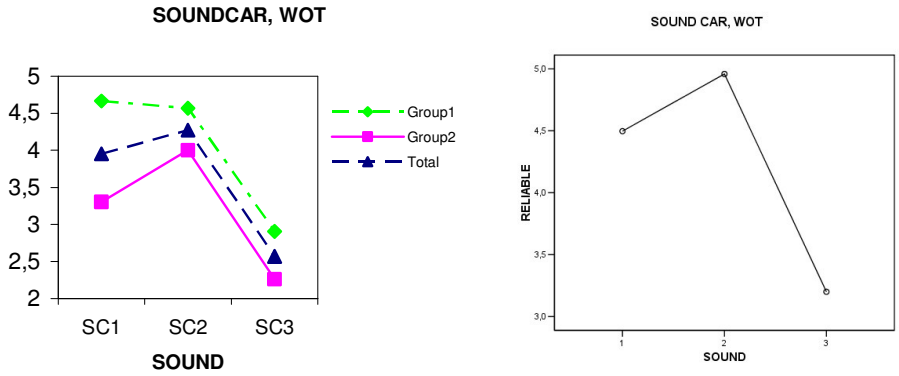


Figure 5.25 Desirable, WOT SC Reliable, WOT SC

The eighth adjective, reliable has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference between the natural WOT sound and the WOT sound +5dB vibration and with the WOT sound without vibration and the WOT sound with

+5dB vibration. The WOT sound without vibration is considered as the most reliable sound while the WOT sound with +5dB is considered to be the least reliable sound (figure 5.25).

In the second part of the questionnaire, a question about how much the participant liked the sound were asked. The second part has no significant difference between the sounds; therefore no significant result can be drawn.

In the third part the participants answered a question with help of the VCC scale; what they thought that the potential customer would think about the sound. There is a significant difference between the sounds at 0,1 %. There is no significant difference between the genders but there is a significant difference between the groups at 4,1%. Group one, that started the listening test in the listening room, has answered slightly more positive. In general both groups consider that the WOT sound without vibration is the most attractive sound among the customers while the WOT sound with +5dB vibration is the least attractive sound among the customers (figure 5.26).

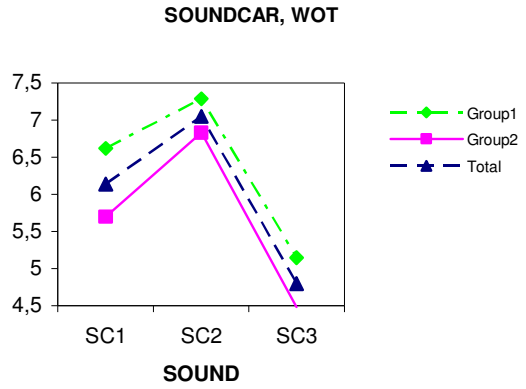


Figure 5.26 VCC scale for subjective rating, WOT SC

5.2.2 Analysis of the idle sounds

The third analysis in the SoundCar is between the idle sounds:

1. Idle parking with natural vibration (SC1)
2. Idle parking without vibration (SC2)
3. Idle parking vibration –10dB order 93 (SC3)

The procedure for the analysis between the idling sounds is the same as the previous analysis that is done in the listening room/ SoundCar.

In the first part eight describing adjectives is included and analysed. The first adjective, powerful has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference between the idle sound with natural vibration and the idle sound without vibration. In figure 5.27 one can see that the idle sound without vibration is the least powerful idle sound and the natural idle sound is the most powerful idle sound.

The second adjective, unpleasant has a significant difference between the sounds at 0,1%. In a pair wise comparison there are a significant difference between natural idle parking and the idle parking without vibration and between the idle parking without vibration with idle parking with vibration –10dB order 93. The idle sound without vibration is considered as the

sound that is least unpleasant and the idle that is natural is considered as the most unpleasant sound (figure 5.27).

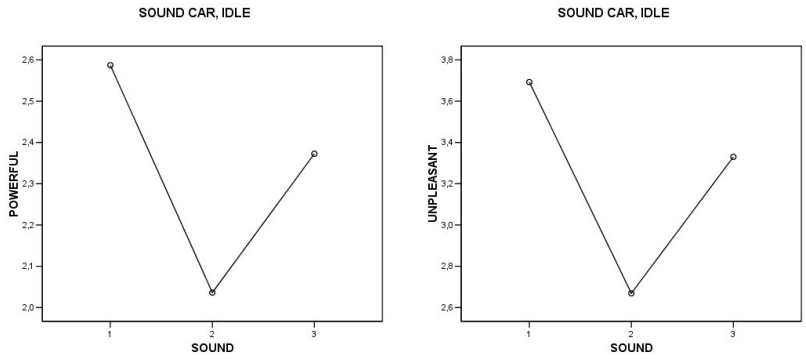


Figure 5.27 Powerful, idle SC Unpleasant, idle SC

The third adjective, roughness has a significant difference between the sounds at 0,1%. There is a significant difference between the genders at 2,9% but no significant difference between the groups. In a pair wise comparison there are significant differences between the normal idle sound and the idle sound without vibration and between the idle sound without vibration and idle parking with vibration –10dB order 93. In figure 5.28 one can see that the males' thought that the idle sounds were rougher compared to the females. In general both genders thought that the idle sound without vibration is the sound that is least rough. The males and females has answered differently on which sound that is the most rough, males think that the natural idle sound is the most rough one while the females thinks that the idle sound with vibration –10dB order 93 is the most rough idle sound.

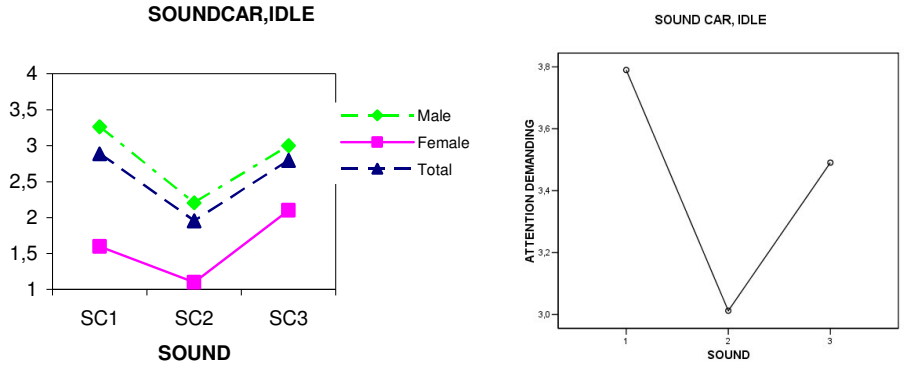


Figure 5.28 Roughness, idle SC Attention demanding, idle SC

The fourth adjective, attention demanding has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison it is a difference between the natural idle sound and the idle sound without vibration. The idle sound without vibration is considered to be the least attention demanding idle sound while the natural idle sound is considered to be the most attention demanding sound (figure 5.28).

The fifth adjective, tonality has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison one cannot see any significant differences between the sounds. The natural idle sound is

considered to have the highest amount of tonality while the filtered idle sound has the lowest amount of tonality (figure 5.29).

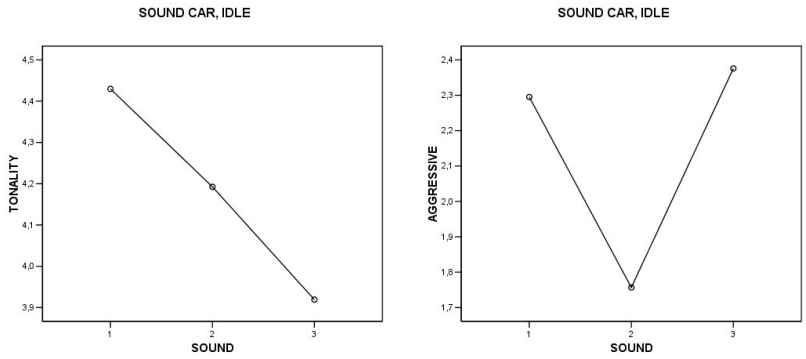


Figure 5.29 Tonality, idle SC Aggressive, idle SC

The sixth adjective, aggressive has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference between the natural idle sound and the idle sound without vibration and between the idle sound without vibration and the filtered idle sound. The idle sound without vibration is considered to be least aggressive while the filtered sound is considered to be the most aggressive sound (figure 5.29).

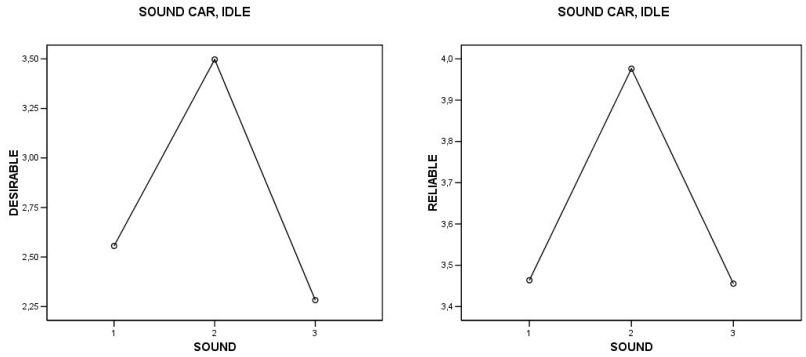


Figure 5.30 Desirable, idle SC Reliable, idle SC

The seventh adjective, desirable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison there is a significant difference between the natural idle sound and the idle sound without vibration and between the idle sounds without vibration with the idle sound that is filtered. The idle sound without vibration is considered to be the most desirable idle sound; while the filtered idle sound is considered to be the least desirable sound (figure 5.30).

The eighth adjective, reliable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison one can see a difference between the natural idle sound and the idle sound without vibration. The idle sound without vibration is considered to be the most reliable sound while the two other idle sounds is considered to be equally not reliable sound (figure 5.30).

In the second part of the questionnaire the participants answered if they liked the sound. In that particular question there is no significant difference between the sounds, therefore no conclusion can be drawn from the question.

In the third part the participant estimated what they thought that a potential customer would think about the sound. The significant difference between the sounds is 0,1%, there is no significant difference between the genders or between the groups. In a pair wise comparison there is significant difference between the natural idle sound and the idle sound without vibration and between the idle sound without vibration and the filtered idle sound. The idle sound without vibration is considered to be the sound that the potential customer would like the most between the three idle sounds. The natural idle sound and the idle sound that is filtered are at a shared place for the least wanted sound for a potential customer. All sounds are rated below 6, and that means that none of the sounds are being approved.

5.2.3 Analysis of the transient sounds

The fourth and the last analysis made in the SoundCar is between the transient sounds:

1. Transient with natural vibration (SC1)
2. Transient without vibration (SC2)
3. Transient with vibration +5dB (SC3)
4. Transient with vibration –5dB (SC4)

The analysis made with the transient sounds are the same as previous analyses made in the listening room /SoundCar. The first part includes eight describing adjectives, the second part is a question about how much the participants liked the sound and the third part is a question about what the potential customer would think about the sound.

The first adjective, powerful has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between:

- The natural transient sound and the transient sound without vibration and
- The transient sound without vibration and transient sound with +5dB vibration
- The transient sound without vibration and transient sound with –5dB vibration

The participant found that the transient sound with natural vibration and the transient sound with –5dB vibration as equal in the judgment of how powerful the sounds are (figure 5.31). As expected the transient sound without vibration is considered to be the least powerful sound while the transient sound with +5dB is considered to the most powerful sound.

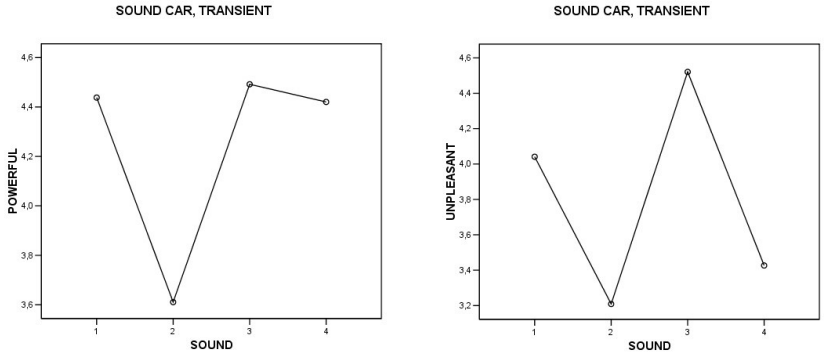


Figure 5.31 Powerful, transient SC Unpleasant, transient SC

The second adjective, unpleasant has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between:

- The natural transient sound and the transient sound without vibration
- The transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and with the transient sound with –5dB vibration

The transient sound with higher amount of vibration is considered to be the most unpleasant sound while the transient sound without vibration is considered to be the least unpleasant sound (figure 5.31).

The third adjective, roughness shows a significant difference between the transient sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are differences between:

- The natural transient sound and the transient sound without vibration
- The transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and with the transient sound with –5dB vibration

As expected, once again the transient sound with +5dB is considered to be the sound with higher amount of roughness while the transient sound without vibration is considered to have less roughness (figure 5.32).

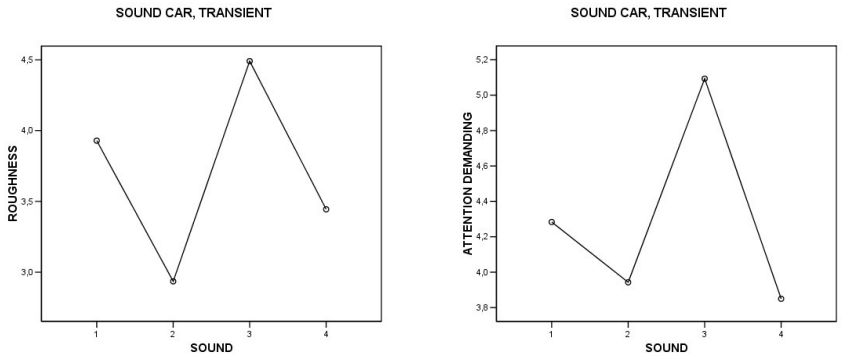


Figure 5.32 Roughness, transient SC Attention demanding, transient SC

The fourth adjective, attention demanding has a significant difference between the transient sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are significant differences between:

- The natural transient sound and the transient sound with +5dB vibration
- Transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and with the transient sound with –5dB vibration

The transient sound with +5dB vibration is considered to be the sound that is the most attention demanding sound, while the transient sound with –5dB vibration is the sound that is the least attention demanding sound (figure 5.32).

The fifth adjective, tonality has a significant difference between the sounds at 0,1%. There is a significant difference between the genders at 3,3% but no significant difference between the groups. In a pair wise comparison there is a significant difference between the natural transient sound and the transient sound without vibration. In general the females thought that there

were higher tonality in the transient sounds than the males (figure 5.33). The females considered that the tonality were lower when no vibration were involved while the males rated the sounds as quite constant.

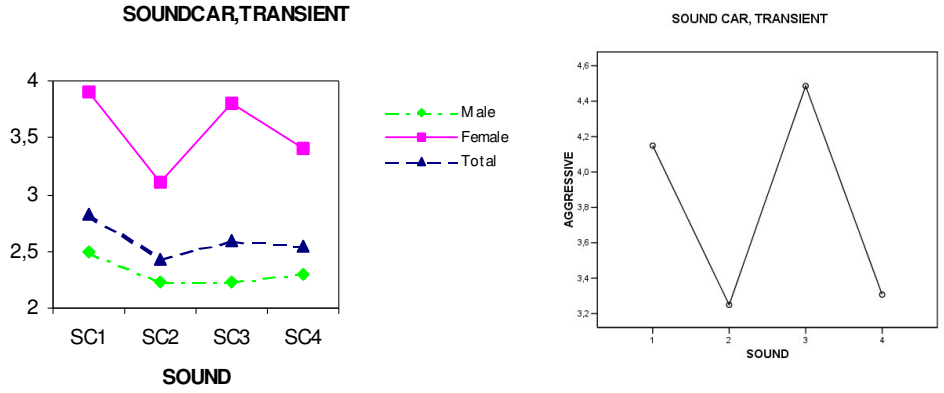


Figure 5.33 Tonality, transient SC Aggressive, transient SC

The sixth adjective, aggressive has a significant difference between the sounds at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are significant differences between:

- The natural transient sound and the transient sound without vibration
- The natural transient sound and the transient sound with –5dB vibration
- The transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and the transient sound with –5dB vibration

As expected the most aggressive sound is considered to be the transient sound with +5dB vibration while the least aggressive sound is the transient sound without vibration/transient sound with –5dB vibration (figure 5.33).

The seventh adjective, desirable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are significant differences between:

- The natural transient sound and the transient sound with –5dB vibration
- The transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and the transient sound with –5dB vibration

The transient sound without vibration and the transient sound with –5dB vibration are considered to be the most desirable sound among the participants while the least desirable sound is the transient sound with +5dB vibration (figure 5.34).

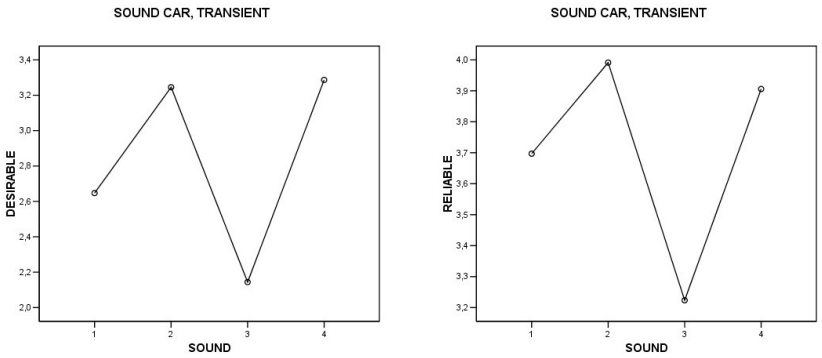


Figure 5.34 Desirable, transient SC Reliable, transient SC

The eighth adjective, reliable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups and there are no significant differences in a pair wise comparison between the transient sounds. The transient sound without vibration and the transient sound with –5dB vibration are considered to be the most reliable transient sounds while the transient sound with +5dB is considered to be the least reliable sound.

In the second part of the questioner the participants were asked if they liked the sound. The significant difference for that specific question is 0,1%. There are no significant differences between the genders or between the groups. In a pair wise comparison between the sounds there are significant differences between:

- The natural transient sound ant the transient sound without vibration
- The transient sound without vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and the transient with –5dB vibration

The participants liked the transient sound without vibration and the transient sound with –5dB vibration the most while the transient sound with +5dB were least liked. But even though the transient sound has less vibration the grades were not high for the transient sounds (figure 5.35).

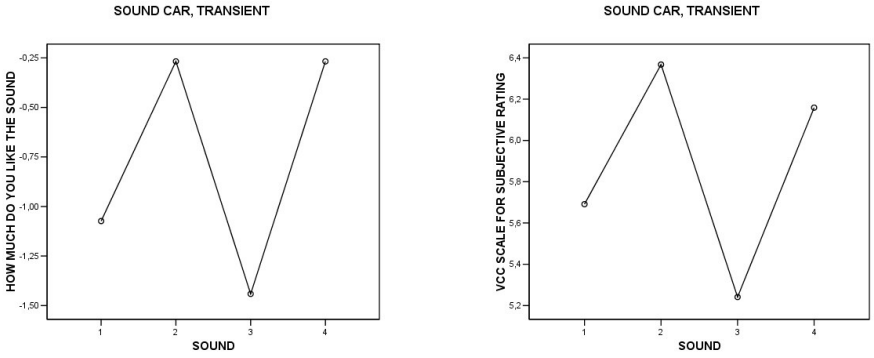


Figure 5.35 How much do you like the sound, transient SC VCC scale for subjective rating, transient SC

The last part of the questioner was about what the potential customer would think about the sound. The significant difference for this question is 0,1% and there are no significant differences between the genders or between the groups. In pair wise comparisons between the sounds there are a significant difference between:

- The natural transient sound and the transient sound without vibration
- The transient sound with out vibration and the transient sound with +5dB vibration
- The transient sound with +5dB vibration and the transient sound with –5dB vibration

The participants considered that a potential customer would like transient sound without vibration the most and the transient sound with +5dB least (figure 5.35).

5.3 Listening room vs. SoundCar

To see differences of the perceptions between the sounds a comparison is made between the listening room and the SoundCar. The first thing that is looked at is to see if there is a significant difference between the sounds. Three different types of sounds were compared:

1. Transient sound
2. Idle sound
3. WOT sound

In the beginning of the thesis it was meant to have BTPA sound in the SoundCar test, due to the limitation of time and because there exists no old record for a BTPA sound with vibration it was not possible to include a BTPA sound in the SoundCar test. In this evaluation part it will be possible to see how much vibration can affect the perception of a person. The analysis made for the three types of sounds are the same as the previous analyses, first part is eight describing adjectives, the second part is a question about how much the participant liked the sound and the third part is a question about what the potential customer would think about the sound.

5.3.1 Analysis of the transient sounds

The first analysis is between the transient sounds:

1. Transient sound from the listening room (LR1)
2. Transient sound with vibration (SC1)
3. Transient sound without vibration (SC2)
4. Transient sound with +5dB vibration (SC3)
5. Transient sound with –5dB vibration (SC4)

The first adjective, powerful has a significant difference between the sounds at 0,01%. There are no significant differences between the genders or between the groups. As can be seen from figure 5.36 the sounds with vibration have been considered as more powerful. The sound without vibration that is played in the SoundCar is considered to be the least powerful sound of the transient sounds.

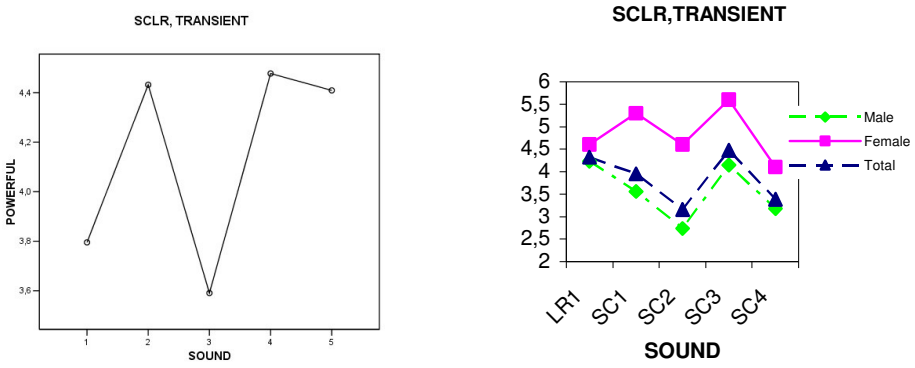


Figure 5.36 Powerful, transient SCLR Unpleasant, transient SCLR

The second adjective, unpleasant has a significant difference between the sounds at 0,1%. There are a significant difference between the genders at 0,9% and a significant difference between the groups at 4,4%. The largest difference between the groups as one can see in figure 5.36 is that group one, that started to have the test in the listening room has answered slightly higher than group two, that started in the SoundCar. The difference between the groups is for the transient sound from the listening room, where group one has rated the sound with a 6 in the scale while group 2 has rated the sound with a 3 in the scale. The largest difference between the genders is that the females found the sound more unpleasant than the males. The participants consider that the transient sound with +5dB as the most unpleasant sound. The least unpleasant sound differs among the genders; the females rated the transient sound with –5dB as the least unpleasant sound while the males found the sound from the listening room as the least unpleasant sound.

The third adjective, roughness has a significant difference between the sounds at 0,1%. There is a significant difference between the genders at 4,2% but no significant difference between the groups. The females found the transient sounds rougher than the males. The female considers that the roughest sound is the natural transient sound with vibration while the males considers the transient sound with +5dB as the most rough sound. The least rough sound differs between the genders; the females rated the sound in the listening room as the least rough sound while the male rated the sound without vibration in the SoundCar as the least rough sound (figure 5.37).

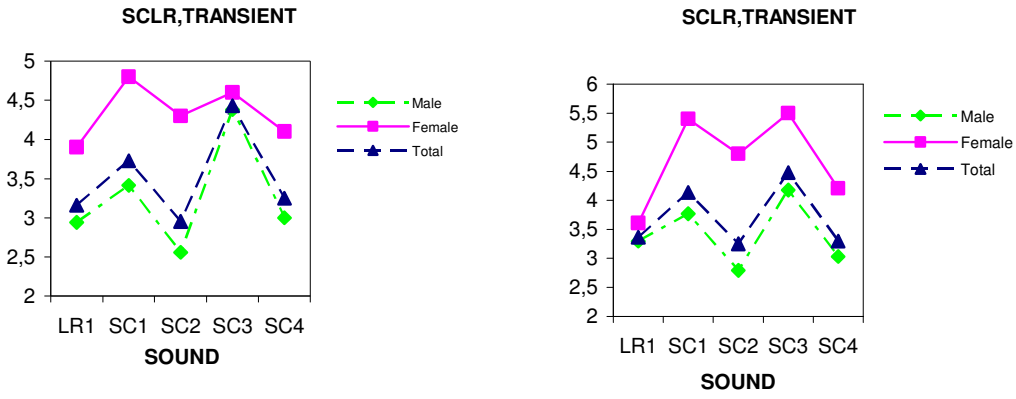


Figure 5.37 Roughness, transient SCLR Attention demanding, transient SCLR

The fourth adjective, attention demanding has a significant difference between the sound at 0,1%. There is a significant difference between the genders at 0,7% but there is no significant difference between the groups. In general the females considers the transient sound as more attention demanding than the males. The most attention demanding sound for both genders is the transient sound +5dB vibration. The least attention demanding sound differs between the genders; the females found the transient sound with –5dB least attention demanding while the males found the transient sound without vibration, SoundCar as the least attention demanding sound (figure 5.37).

The fifth adjective, tonality has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The most tonal transient sound is the natural transient sound with vibration, SoundCar (figure 5.38). The transient sound that is considered to have few tonal components is the transient sound without vibration, SoundCar. Even though there are differences between the transient sounds the participants do not think that the tonality changes much with the vibration, the participants rated the tonality in the scale between 2-3.

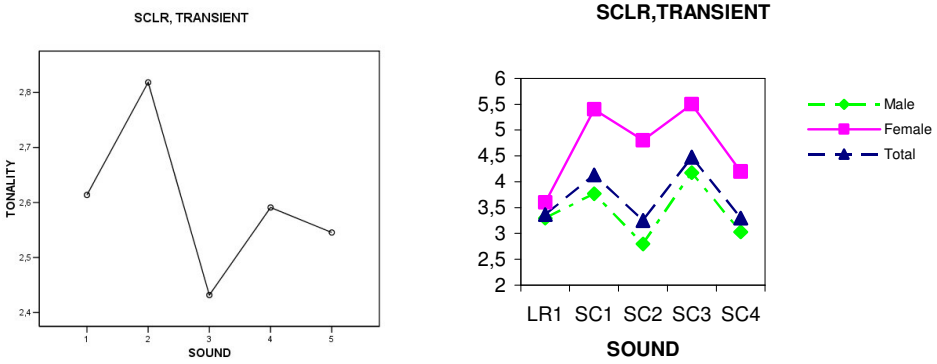


Figure 5.38 Tonality, transient SCLR Aggressive, transient SCLR

The sixth adjective, aggressive has a significant difference at 0,1%. There is a significant difference between the genders at 0,3% but no significant difference between the groups. The female participants found the transient sound more aggressive than the male participants (figure 5.38). The most aggressive transient sound differs between the genders; the females found the transient sound with natural vibration and the transient sound with +5dB vibration

as the most aggressive transient sound while the males consider the transient sound with +5dB vibration as the most aggressive. The least aggressive for the female participants is the transient sound played in the listening room and for the male participants the transient sound without vibration, SoundCar is considered to be the least aggressive sound.

The seventh adjective, desirable has a significant difference at 0,1%. There is a significant difference between the genders at 0,8% and there is a significant difference between the groups at 1,0%. The female participants found the transient sounds less desirable than the male participants (figure 5.39). The most desirable sound for the male participants is the transient sound without vibration, and the transient sound with –5dB vibration. The female participants did not give high grades for the adjective desirable; they considered that the transient sound played in the listening room and the transient sound with –5dB, SoundCar as the most desirable sound. Group two, that started the test in the SoundCar is in general more positive for all transient sounds compared to group one, that started with the test in the listening room. The largest difference between the groups for the transient sounds is for the first sound, the transient sound, listening room, where group two is much more positive than group one to the sound.

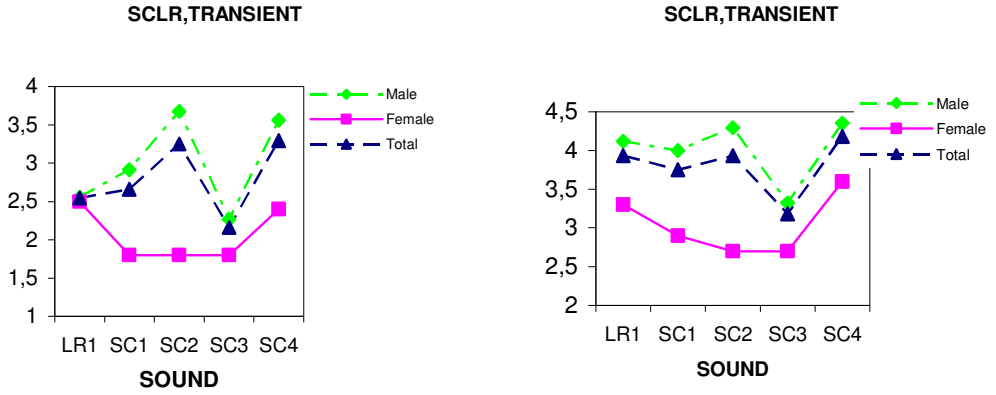


Figure 5.39 Desirable, transient SCLR Reliable, transient SCLR

The eighth adjective, reliable has a significant difference at 0,1%. There is a significant difference between the genders at 2,2% but no significant difference between the groups. In general the male participants found the transient sounds as more reliable than the female participants (figure 5.39). The most reliable sound, which includes both genders, is the transient sound –5dB vibration and the least reliable sound is the transient sound +5dB vibration. The largest difference between the genders for transient sound is the transient sound without vibration, SoundCar; the male participants found it quite reliable while the female participants did not find it reliable at all.

The second part of the questionnaire was to answer a question about how much the participant liked the sound. The significant difference for the question is 0,1%. There is a significant difference between the genders at 0,2% and there is a significant difference between the groups at 3,3%. The male participants like the transient sound slightly more than the female participants (figure 5.40). There is a little difference between the groups, group two, that started in the SoundCar, has rated the transient sounds higher than group one, that started in the listening room. The largest difference between the groups is for the transient sound that is played in the listening room; group two has rated the sound more positive than group one, which is less satisfied with the sound. In general the transient sound with –5dB is the most liked transient sound while the transient sound with +5dB is the least liked sound.

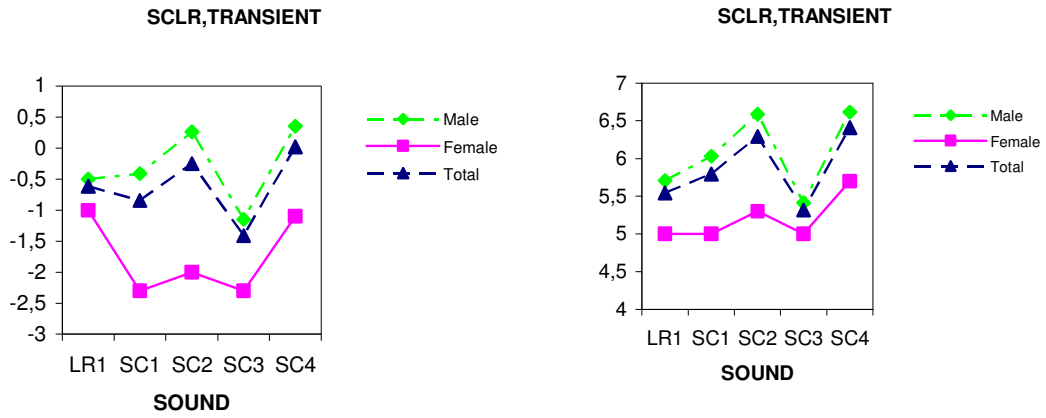


Figure 5.40 How much do you like the sound, transient SCLR VCC Scale for subjective rating, transient SCLR

The third part in the questionnaire is to answer a question about what the potential customer would think about the sound. The question has a significant difference at 0,1%. There is a significant difference between the genders at 2,7% but no significant difference between the groups. The females and the males' thought similar about the transient sounds, the only difference was that the females have rated the transient sounds lower (figure 5.40). In general the most liked sound for a potential customer would be the transient sound with –5dB vibration and the less liked sound for a potential customer would be the transient sound with +5dB vibration.

5.3.2 Analysis of the idle sounds

The second analysis made between the listening room and SoundCar is between the idle sounds. The analysis between the idle sounds is the same as previous performed analyses above. The analysis will consist of three parts, where the first part is eight describing adjectives and part two and three involves questions about how much the participant liked the sound/ what would a potential customer think about the sound. Six different idle sounds are compared:

1. Idle parking (LR1)
2. Idle parking -10dB, order 93 (LR2)
3. Idle parking bandstop, order 95 (LR3)
4. Idle parking with vibration (SC1)
5. Idle parking without vibration (SC2)
6. Idle parking vibration –10dB order 93 (SC3)

The first adjective, powerful has a significant difference at 0,1%. There is no significant difference between the genders but there is a significant difference between the groups at 1,6%. Group one, that started the test in the listening room are more positive to the idle sounds than group two that started with the test in the SoundCar (figure 5.41). In general the participants consider the Idle sounds with natural vibration as the most powerful sound while the least powerful sound is considered to be the idle parking sound in the listening room.

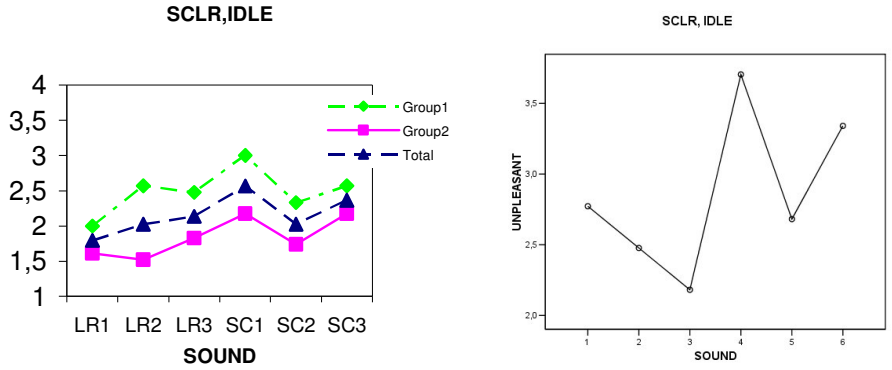


Figure 5.41 Powerful, idle SCLR Unpleasant, idle SCLR

The second adjective, unpleasant has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. In general the most unpleasant sound among the participants is considered to be idle sound with natural vibration, SoundCar, while the least unpleasant sound is considered to be the idle sound, changed with a filter (bandstop, order 95), (figure 5.41).

The third adjective roughness has as significant difference at 0,1%. There are no significant differences between the genders or between the groups. In general the participants considered the idle sound with natural vibration, SoundCar as the roughest sound while the least rough sound were considered to be the idle parking sound, changed with a filter (-10dB, order 93), (Figure 5.42).

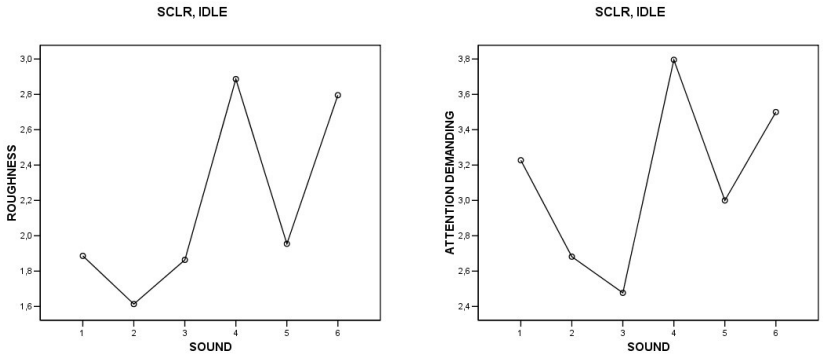


Figure 5.42 Roughness, idle SCLR Attention demanding, idle SCLR

The fourth adjective, attention demanding has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The most attention demanding sound is considered to be the idle sound with natural vibration, SoundCar while the least attention demanding sound is the idle sound changed with a filter (bandstop, order 95), (figure 5.42).

The fifth adjective tonality has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. There are no large differences between the rates for the sounds in the listening room/SoundCar (figure 5.43). Tonality is perceived slightly higher for the participants in the SoundCar than for the participants in the listening room.

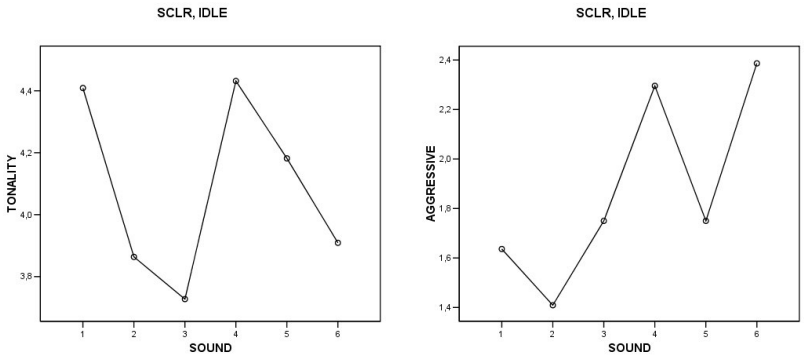


Figure 5.43 Tonality, idle SCLR Aggressive, idle SCLR

The sixth adjective, aggressive has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The participants have rated the idle sounds played in the listening room lower compared to the sounds played in the SoundCar (figure 5.43). The idle sounds with vibration are rated as more aggressive compared to the sounds without vibration.

The seventh adjective, desirable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The participants have rated the idle sounds from the listening room as more desirable than the idle sounds in the SoundCar (figure 5.44). The most desirable idle sound in the listening room is the idle sound with a bandstop filter, order 95, and the most desirable idle sound in the SoundCar is the idle sound without vibration. The natural idle sound is the least desirable sound among the participants.

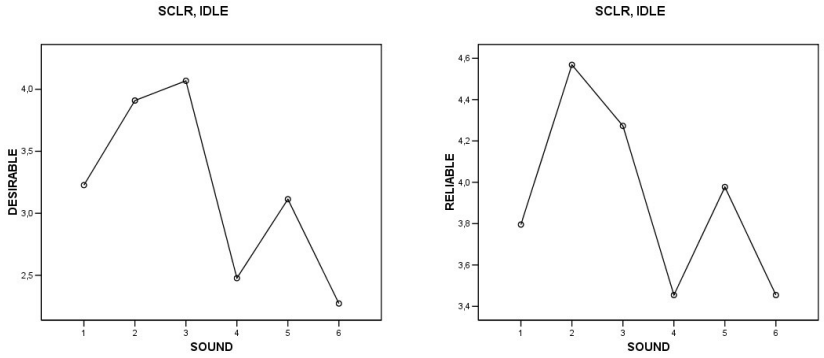


Figure 5.44 Desirable, idle SCLR Reliable, idle SCLR

The eighth adjective, reliable has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The idle sounds played in the SoundCar are considered to be less reliable than the idle sounds played in the listening room (figure 5.44). The most reliable idle sound in the SoundCar is the idle sound without vibration and the most reliable sound in the listening room is the idle sound, which is changed with -10dB, order 93.

The second part of the questionnaire is to answer a question about how much the participants liked the sound. This question has no significant difference; therefore one cannot draw a valid conclusion.

The third part of the questionnaire was to answer a question about what a potential customer would think about the sound. This question has a significant difference at 0,1%. There are no

significant differences between the genders or between the groups. The idle sound played in the SoundCar is less liked compared to the idle sounds played in the listening room (figure 5.45). The most liked sound for the potential customer would be the idle sound –10 dB, order 93, played in the listening room while the least liked idle sound is the idle sound –10 dB, order 93 with vibration.

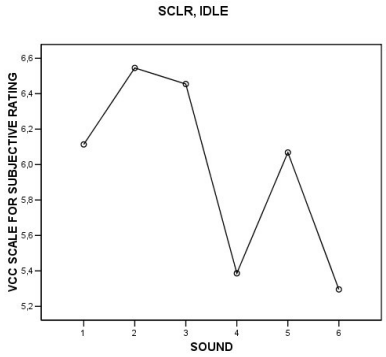


Figure 5.45 VCC Scale for subjective rating, idle SCLR

5.3.3 Analysis of the WOT sounds

The third analysis made between the listening room and the SoundCar is between the WOT sounds. The analysis for the WOT sounds is the same as the previous analyses made before, first there will be eight describing adjectives, secondly a question is asked about how much the participants liked the sound and thirdly the participants answered the question about what a potential customer would think about the sound. The WOT sounds involved in the analysis between the listening room and SoundCar:

1. Gear 3 WOT (listening room), (LR1)
2. WOT with natural vibration (SoundCar), (SC1)
3. WOT without vibration (SoundCar), (SC2)
4. WOT with vibration +5dB (SoundCar), (SC3)

The first adjective, powerful has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The most powerful sound is considered to be the WOT sound played in the listening room, while the least powerful sound is the WOT sound without vibration (figure 5.46). The participants considered the WOT sound with natural vibration and the WOT sound with +5dB vibration as equally powerful.

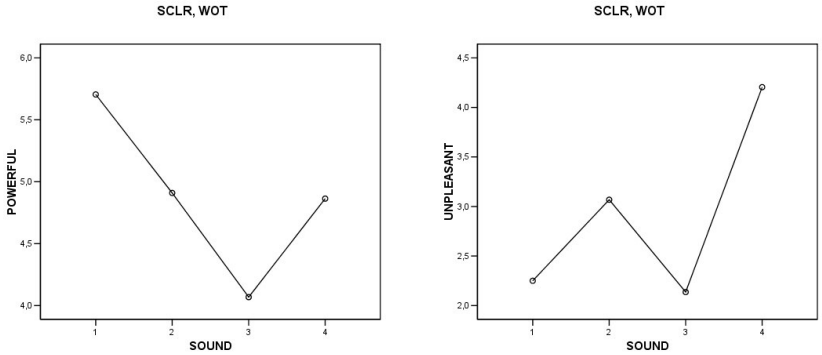


Figure 5.46 Powerful, WOT SCLR Unpleasant, WOT SCLR

The second adjective, unpleasant has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The WOT sound played in the listening room and the WOT sound without vibration, SoundCar is considered to be the least unpleasant sounds while the WOT sound with +5dB vibration is considered to be the most unpleasant sound (figure 5.46).

The third adjective, roughness has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The least rough sound is considered to be the WOT sound without vibration, SoundCar (figure 5.47). The other WOT sounds are rated quite similar, but there are a slightly difference between them, the WOT sound with +5dB vibration is considered to be rougher than the other WOT sounds.

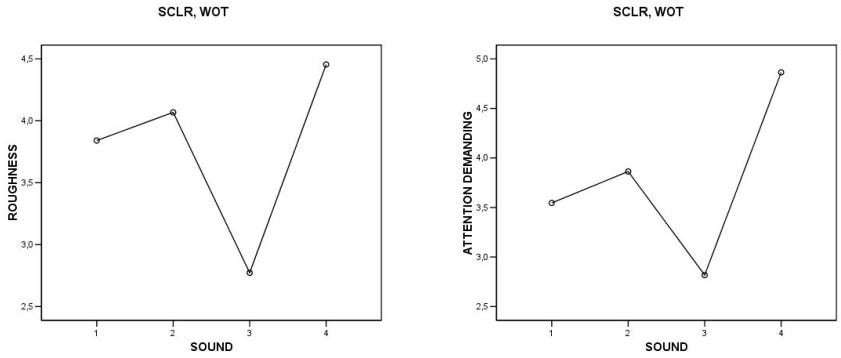


Figure 5.47 Roughness, WOT SCLR Attention demanding, WOT SCLR

The fourth adjective, attention demanding has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The WOT sound with +5dB vibration, SoundCar is considered to be the most attention demanding sound while the WOT sound without vibration (SoundCar) is considered to be the least attention demanding sound (figure 5.47). The natural WOT sound (listening room) and the natural WOT sound with vibration is perceived as close as equally attention demanding.

The fifth adjective, tonality has a significant difference at 0,1%. There is no significant difference between the genders but there are a significant difference between the groups at 2,9%. The differences between the groups are not large (figure 5.48). Group two that started with the test in the SoundCar has rated the sounds slightly higher than group one that started the test in the listening room. In general, the WOT sound without vibration is considered to have the highest amount of tonality, while the WOT sound with +5dB vibration (SoundCar) is considered to have a small amount of tonality in the sound. The largest difference between the groups is between the natural WOT sound with vibration (SoundCar), the participants in group one have perceived less tonality while group two perceived the same amount of tonality as for the sound without vibration (SoundCar).

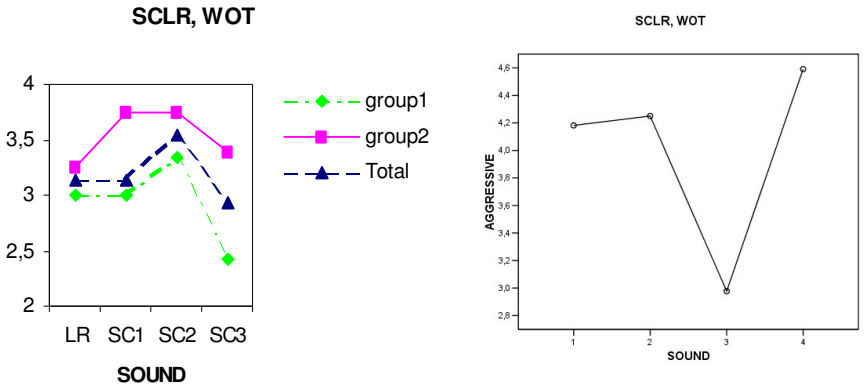


Figure 5.48 Tonality, WOT SCLR Aggressive, WOT SCLR

The sixth adjective, aggressive has a significant difference at 0,1%. There are no significant differences between the genders or the groups. The WOT sound played in the listening room is considered to be equally aggressive as the natural WOT sound with vibration played in the SoundCar (figure 5.48). The least aggressive WOT sound is the WOT sound without vibration played in the SoundCar and as expected, the most aggressive WOT sound is the WOT sound with +5dB vibration (SoundCar).

The seventh adjective, desirable has a significant difference at 0,1%. There is no significant difference between the genders but it is a significant difference between the groups at 1,8%. The differences between the groups are very small (figure 5.49). In general the most desirable sound is the WOT sound played in the listening room while the least desirable sound is the WOT sound with +5dB vibration (SoundCar). The largest difference between the groups is for the WOT sound with natural vibration (SoundCar); Group two, that started the test in the SoundCar found the WOT sound with natural vibration less desirable than group one that started the test in the listening room.

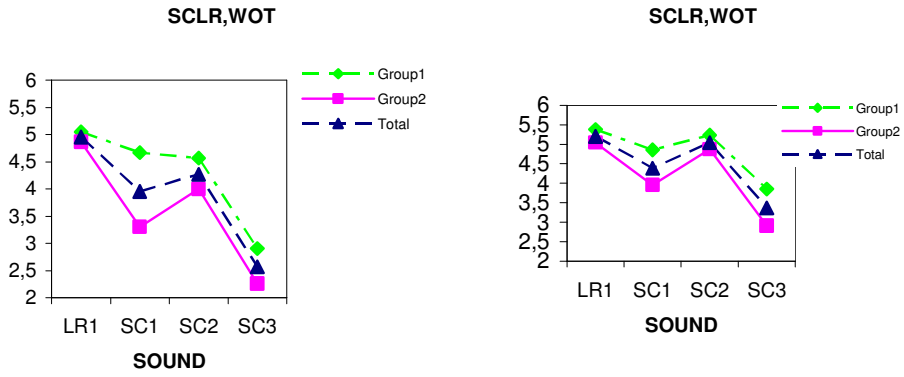
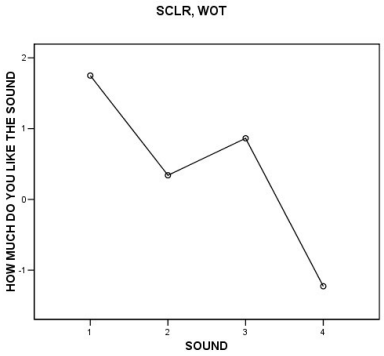


Figure 5.49 Desirable, WOT SCLR Reliable, WOT SCLR

The eighth adjective, reliable has a significant difference at 0,1%. There is no significant difference between the genders but there is a significant difference between the groups at 3,7%. In general the WOT sound played in the listening room and the WOT sound without vibration played in the SoundCar is considered to be the most reliable WOT sounds while the WOT sound with +5dB vibration (SoundCar) is considered to be the least reliable sound (figure 5.49). The largest difference between the groups is between the WOT sound with vibration

(SoundCar) and the WOT sound with +5dB vibration (SoundCar), where group one (started the test in the listening room) have graded the WOT sounds as more reliable than group two (started the test in the SoundCar).



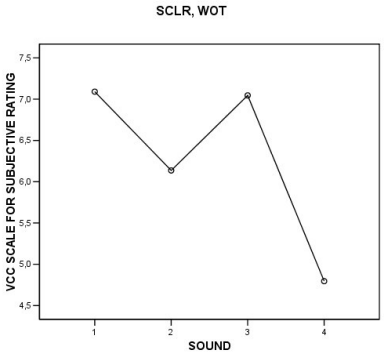


Figure 5.50 How much do you like the sound, WOT SCLR VCC Scale for subjective rating, WOT SCLR

The second part of the questionnaire was to answer a question about how much the participant liked the sound. The question has a significant difference at 1,4%. There are no significant differences between the genders or between the groups. The participants liked the WOT sound played in the listening room the most and the WOT sound with +5dB vibration (SoundCar) least (figure 5.50).
The third part of the questionnaire was to answer a question about how a potential customer would think about the sound. The question has a significant difference at 0,1%. There are no significant differences between the genders or between the groups. The WOT sound in the listening room and the WOT sound without vibration (SoundCar) is considered to be the most liked sound among potential customers while the WOT sound with +5dB vibration is the least liked sound among the potential customers (figure 5.50).

5.4 Reality

The forth and last group analysis is the evaluation of the reality of the sounds. Questions about the reality were asked both in the listening room test and in the SoundCar test. In the listening room the reality questions came after all sounds were played. In the SoundCar test the reality questions came after each sound. In the listening room there were two questions; the first question asked how similar to reality the situation was and the second question asked how present the participants thought they were in the situation. Both questions had a scale between 0-100, where 0 meant not like reality/not present at all and 100 meant like reality/very present. The SoundCar test had three reality questions; two of them were the same as in the listening room. The third question was about how convincing the feeling was to actually sit into a car was. The scale for the third question goes between 0-10, where 0 meant not convincing at all and 10 meant very convincing. The questions were developed from Daniel Västfjäll, psychologist.

The evaluation of the reality is to calculate the mean value of each question and make a comparison between the mean values.

Two different analyses are made between the reality questions:

1. SoundCar: with vibration/ without vibration
2. SoundCar ↔ Listening room: With/without vibration

If only looking to the results from the SoundCar there are differences between the sounds with/without vibrations. All three questions about the reality have a higher mean value compared to the sounds without vibration. The participants have rated the reality question and the presence question quite high in the SoundCar. For the third question, how convincing the feeling was to actually sit into a car the participants have rated the sounds with vibration very high while the sound without vibration got a slightly lower grade.

Table 5.1 SoundCar, with/without vibration

SoundCar	Mean value
R1 with vibration	75,99
R1 without vibration	61,29
R2 with vibration	7,36
R2 without vibration	5,57
R3 with vibration	79,37
R3 without vibration	64,22

SoundCar↔Listening room with/without vibration

SoundCar ↔Listening room	Mean value
R1 with vibration (SC)	71,77
R1 without vibration (LR)	59,36
R3 with vibration (SC)	75,19
R2 without vibration (LR)	60,55

If looking to the results from the comparison between the SoundCar with vibration and the listening room one can see that the mean values for the sounds with vibration are higher than for the sounds without vibration. The participants found the sounds with vibration quite similar to the reality and the participant felt very present during hearing the sound with vibration compared to the sound without vibration.

The last analysis for the reality is made between the sounds in the SoundCar without vibration and the listening room. The mean value is slightly higher for the sounds from the SoundCar. The reality and the feeling of presence are not high for the sound without vibration. But out of the mean values there is a little difference to perform a listening test in a SoundCar compared to a listening room.

Table 5.2 SoundCar↔Listening room without vibration

SoundCar ↔ Listening room	Mean value
R1 without vibration (SC)	61,29
R1 without vibration (LR)	59,36
R3 without vibration (SC)	64,22
R2 without vibration (LR)	59,36

5.5 General Findings

By the tables below it is possible to see if there are differences between the genders/ groups and which sound stimuli of the transient sound that was the "most" and "least" of each adjective/ question:

- Table 5.3 Transient sound/ stimuli
- Table 5.4 Idle sound/ stimuli
- Table 5.5 WOT sound/ stimuli

5.5.1 Transient sound/ stimuli

Out of the test for the transient sound/ stimuli one can see that the participants do not think that the tonality changes with the vibration. In general the male participants liked the transient sounds more than the female participants and group two, that started with the test in the SoundCar has rated the sounds/stimuli higher than group one, that started with the test in the listening room, for the question if they liked the sounds/ stimuli.

For the second adjective, unpleasant, group one that started with the test in the listening room has rated the sounds/ stimuli slightly higher than group two, that started with the test in the SoundCar. The females rated the transient sound as:

- More unpleasant than the males
- More rough than the males
- More attention demanding than the males
- More aggressive than the males
- Less desirable than the males
- Less reliable than the males

Table 5.3 Transient sound/ stimuli

	Gender [Sig.]	Most [F=Female] [M=Male]	Least [F=Female] [M=Male]
Powerful	0%	+5dB	SC, without vibration
Unpleasant	0,9%	+5dB	F: -5dB M: LR
Rough/Roughness	4,2%	F: natural, SC M: +5dB	F: LR M: without, SC
Attention demanding	0,7%	+5dB	F: -5dB, SC M: without, SC
Tonal/ tonality	0%	Natural, SC	Without SC
Aggressive	0,3%	F: natural SC, +5dB M: +5dB	F: LR M: without SC
Desirable	0,8%	F: LR, -5dB M: without, SC, -5dB	F: +5dB Male: normal, SC without, SC, +5dB, SC
Reliable	2,2%	-5dB	+5dB
Question 2:	0,2%	-5dB	+5dB
Question 3:	2,7%	-5dB	+5dB

5.5.2 Idle sound/ stimuli

There is no significant difference between the genders for the idle sounds, but there is as significant difference between the groups for the adjective powerful at 1,6%, where group one (started the test in the listening room) has rated the idle sounds/ stimuli slightly higher than group two (started with the test in the SoundCar). Out of table 5.4 below one can see that the idle sound with natural vibration is perceived as less good among the participants and that the filtered idle sounds are perceived as a more attractive sound.

Table 5.4 Idle sound/ stimuli

	Gender [Sig.]	Most [F=Female] [M=Male]	Least [F=Female] [M=Male]
Powerful	0%	Natural vibration, SC	Filter: -10dB, order 93, LR
Unpleasant	0%	Natural vibration, SC	Filter: bandstop order 95, LR
Rough/Roughness	0%	Natural vibration, SC	Filter: -10dB, order 93, LR
Attention demanding	0%	Natural vibration, SC	Filter: bandstop order 95, LR
Tonal/ tonality	0%	Natural vibration, SC	Filter: bandstop order 95, LR
Aggressive	0%	-10dB, order 93, sc	Filter: -10dB, order 93, SC
Desirable	0%	Filter, bandstop order 95, LR	Filter: -10dB, order 93, SC
Reliable	0%	-10dB, order 93, LR	Natural vibration, SC
Question 2:	-	-	-
Question 3:	0%	Filter: -10dB, order 93, LR	Filter: -10dB, order 93, SC

5.5.3 WOT sound/ stimuli

There is no significant difference between the genders for the WOT sounds but there is a significant difference between the groups for the three adjectives:

- Tonality
- Desirable
- Reliable

Group one that started the test in the listening room has rated the adjectives desirable and reliable slightly higher than group two that started with the test in the SoundCar. For the adjective tonality, group two (started with the test in the SoundCar) has rated the WOT sounds with a higher amount of tonality compared to group one (started with the test in the listening room). In general the WOT sound without vibration is more liked among the participants compared the WOT sounds with vibration.

Table 5.5 WOT sound/ stimuli

	Gender [Sig.]	Most [F=Female] [M=Male]	Least [F=Female] [M=Male]
Powerful	0%	Gear 3 WOT, LR	WOT without vibration, SC
Unpleasant	0%	WOT +5dB, SC	WOT without vibration, SC
Rough/Roughness	0%	WOT +5dB, SC	WOT without vibration, SC
Attention demanding	0%	WOT +5dB, SC	WOT without vibration, SC
Tonal/ tonality	0%	WOT without vibration, SC	WOT +5dB, SC
Aggressive	0%	WOT +5dB, SC	WOT without vibration, SC
Desirable	0%	Gear 3 WOT, LR	WOT +5dB, SC
Reliable	0%	Gear 3 WOT, LR	WOT +5dB, SC
Question 2:	0%	Gear 3 WOT, LR	WOT +5dB, SC
Question 3:	0%	Gear 3 WOT, LR WOT without vibration, SC	WOT +5dB, SC

6 Discussion

As expected there are differences between performing a listening test in a SoundCar vs. listening room, but the differences are not large. In this test the participants were divided into two groups to limit unwanted effects. As have been written previous, the groups started at different positions; group one started the test in the listening room and group two started with the test in the SoundCar. The first time feeling of being in a SoundCar differs among the participants, mostly of them found the SoundCar to be a very fascinating tool while others put down efforts on what was wrong with the car and to find further improvements for the SoundCar. The largest difference between the SoundCar and listening room is that the SoundCar is equipped with vibrations. The vibrations affects the sound in different ways, i.e. could annoying sound/tonality in some extent in sound be less annoying if having a higher amount of vibration connected to the sound. The total environment of being seated into the car can affect the answer as well. When performing a listening test for the first time, a lot of participants are quite nervous and cannot relax, some participant were very nervous because they thought it was a hearing test. It was made clear that in a listening test there are no wrong answers, every answer is correct. After performing a listening test once it is much easier to perform a listening test for a second time, even though that the test is not performed at the same place. In these listening tests the participants heard each sound individually, followed by filling the questionnaire. When the page of questions was filled the participant was not allowed to turn back the page when hearing the next sound. A few of the participants found this very annoying, because they found some of the sounds quite similar and wanted to rate similar as they had done before. By performing the test in this sort of way each sound can be compared to each other without being compared during the test. It is very hard not comparing the sounds in our minds, that is how the humans works.

The stimuli/ sound in the SoundCar is perceived as being closer to the reality compared to the sound played in the listening room. When looking to how real a sound feels without vibration, the feeling of reality is not high, but one can see that the participants rated the environment in the SoundCar as more real than the listening room. In some of the analyses there are differences between the groups, which is quite unexpected. That might be caused by the different orders of the test. The participants that started the test in the listening room might have rated the sounds a little bit "higher" than the participants that started the test in the SoundCar, since they did not know what to expect. The participant in the SoundCar might have less expectation of the listening room because they had felt the sound both with and without vibration; they know how the sound "should" sound. The sounds might have felt less loud/weaker compared to when the sound were played in the SoundCar. I.e. the transient sound were perceived as very weak when played in the listening room, if the participant had started with the test in the SoundCar, while the transient sound were perceived as a quite strong sound if the participant had started with the test in the listening room. Even if the SoundCar is a very good tool when performing tests compared to the listening room there are some few improvements that can be made to increase the reality even more:

- Instead of having vibration only at drivers seat and steering wheel, it might increase the effects of reality to put vibration of the car body and gear as well
- Have a ground where it is possible for the car to moving up/down, left/right
- Have loudspeaker in the car instead of headphones

The suggestions of improvement above are only a few examples that can be done to give a higher rate of reality when being seated in a SoundCar.

6.1 Listening room

Four analyses were made of the test in the listening room:

1. All sounds
2. BTPA sounds
3. Idle sounds
4. WOT sounds

The analysis for all the sounds in the listening room has no significant difference between the genders but there are three occasions where there are differences between the groups. In all three occasions group one (started with the test in the listening room) have answered slightly higher than group two (started with the test in the SoundCar). The differences occur for the adjectives powerful, unpleasant and attention demanding. The largest differences between the groups are for the BTPA sounds and for the transient sound and especially for the adjectives unpleasant and attention demanding, where group one found the sounds as more unpleasant and more attention demanding than group two. The reason for this could be due to different reasons, i.e. it could be due to the fact that the participant has heard the sounds before with vibration and besides being seated into a car. There are very few sounds that the potential customer would like according to the participants. The sounds that is rated above 6 in the VCC scale is the WOT sounds and the idle sounds.

The BTPA sound were found as a very strange sound. The sounds did not sound as a normal interior car sound, but more like a heavy vehicle sound. The measured BTPA sounds were recorded at CD1 (chassis dynamometer) and therefore the measured BTPA sound sounded more like a heavy vehicle. When debriefing with the participants after the test about the BTPA sounds some participants said that they could not hear the difference between the sounds, but out of the answers from the questionnaire one can see that there are slightly differences between the BTPA sounds, some expected other not expected at all. For the adjective powerful, there is a significant difference between the genders. The females have rated the BTPA sound as more powerful than the males. The females have rated the BTPA sound, structure borne +4dB as the most powerful sound while the males has rated the BTPA sound, structure borne +6dB as the most powerful sound. It was not expected that the BTPA sound, structure borne +4dB were considered to be more powerful than the BTPA sound, structure borne +6dB. Out of the graph the females did not hear any difference between the BTPA sounds except for the BTPA sound, structure borne +4dB. The males hear a difference between the BTPA sounds. For the adjective, aggressive, the participants have rated the BTPA sound, structure borne +4dB as the most aggressive sound. The BTPA sound, structure borne +6dB was expected to be the most aggressive sound. There are no good explanations for this answer only assumptions can be made. For the adjective attention demanding there is a significant difference between the groups. Group one (started the test in the listening room) has answered slightly higher than group two (started the test in the SoundCar). Group one found the BTPA sound, structure borne +6dB as the most attention demanding sound while group two found the measured BTPA sound as the most attention demanding sound. There are no good explanations for this answer only assumptions can be made. An assumption could be due to that the participants

have hard to hear difference between the measured BTPA sound and simulated BTPA sounds, and the participants rated the sounds with what they felt at that special moment. In general it was very hard for the participants to hear differences between the measured BTPA sound and simulated BTPA sound, which is a very good result because this means that the BTPA method works remarkably well. It seems that the simulated BTPA sound, structure borne +4dB has something that makes the participant reacting to the sound. The most normal thing to expect would be that the simulated sound, structure borne +6dB should be the sound that is less wanted, most aggressive etc. The participants did not know that three of the BTPA sounds were simulated, if they did know the rates of the sounds might have been different. If the participant had a slight hearing damage, it could be hard to hear differences between the BTPA sounds, especially between +2dB ↔ +4dB etc.

The third analysis made in the listening room was between the idle sounds. There are two adjectives, roughness and aggressive, where there are significant difference between the genders and one adjective, powerful, where there is significant difference between the groups. The males found the idle sounds as more rough and aggressive than the females. The explanation for that could be that females and males have different opinions on how a rough/aggressive sound sounds like. It could also be due to that female like idle sounds more than the males. For the adjective powerful, group one (started with the test in the listening room) has rated the idle sounds slightly higher than group two (started with the test in the SoundCar). The reason for the difference between the groups could be due to that group two had heard the sounds with vibration and therefore rated the sounds lower than group one. In general, the most liked sound is the filtered idle sound, -10dB order 93.

The forth and last analysis made was between the WOT sounds. The males liked the WOT sounds more than the females. The reason for that could be that males in nature like more aggressive/sporty sounds, of course this is only an assumption.

6.2 SoundCar

Four analyses were made of test in the SoundCar:

1. All sounds
2. WOT sounds
3. Idle sounds
4. Transient sounds

The first analysis between all sounds has no significant differences between the genders or the groups. As expected the sounds with vibration is rated with higher “reality” in the scales compared to the sounds without vibration.

The second analysis in the SoundCar is between the WOT sounds. In general one can see that the WOT sound without vibration is the sound that is more positive rated in the scales, except for the adjective tonality, where the participant found the sound without vibration to have the highest amount of tonality. The two adjectives, unpleasant and desirable have significant differences between the groups. Group two (started with the test in the SoundCar) has rated the WOT sounds as less unpleasant than group one (started with the test in the listening room). The explanation of this result could be due to that group one already had heard a WOT sound in listening room and because of that the participants in the group might have found the sound with vibration as more unpleasant. For the second adjective, desirable, group one has rated the sounds as more desirable than group two. Group one rates the WOT sound with natural vibration and the WOT sound without vibration as equally desirable while group two rated the WOT sound without vibration as the most desirable sound. The reason for that group two rated

the WOT sound without vibration as the most desirable could be due to that the WOT sounds with vibration affected the participants negative and found that sound without vibration as more attractive sound. For the question where the participants answered what the potential customer would think about the sound, group one have rated slightly higher than group two. In general the groups have the same thoughts about the sounds, and these thoughts were expected; the most liked sound is the WOT sound without vibration and the least liked sound is the WOT sound with +5dB vibration. The reason for the difference between the groups could be very simple, it could be due to that the group two started the test in the SoundCar, and found the WOT sounds less wanted because of the vibration. There is a significant difference between the genders for the adjective tonality. The females have rated the WOT sounds as having a higher amount of tonality than the males. One can speculate on why there is a difference between the genders, it might be that the females are more sensitive to tonal sounds than the males, and that they found the WOT sounds as unpleasant. After the test there were debriefing for those who were interested and felt that they wanted to discuss the sounds. At these occasions a few females sad that they found the WOT sounds as very unpleasant, while the males did not comment the WOT sounds in same extent.

The third analysis made for the SoundCar was between the idle sounds. There is a significant difference between the genders for the adjective roughness. The males rated the idle sounds as slightly rougher than the females. The reason for that could be that the females are more comfortable with the idle sounds compared to the males; maybe the attention is drawn to different components of the sound. Maybe the males listen more to how the engine sounds than the females. In general the most wanted sound is the sound without vibration. This might be seen as strange, because one might think that an idle sound does not include a large amount vibration. In fact, the vibrations appears more visible when being seated into a car without going forward on a road etc. A lot of the participants thought that there was something wrong the amplitude of the vibration, since it appeared and felt very strongly, especially at the steering wheel.

The fourth analysis made for the SoundCar was between the transient sounds. It is very hard to estimate a transient sound because the duration is very short when recording and a transient sound is perceived very differently among humans, some likes the transient sound a lot while others found the transient sound as horrible. There is a significant difference between the genders for the adjective tonality, where the males have rated the transient sound as having a higher amount of tonality. The females have rated the transient sounds as quite similar. The largest difference between the genders is that the females cannot hear any perceptual differences between the transient sound without vibration/transient sound +5dB/ transient sound –5dB. If reasoning about the rating it might have been that the males involve the vibration into the result, normally one would expect a higher amount of tonality if the sound has no vibration, but the males has rated the transient sound without vibration as the sound with least tonality. The author opinion is that it is especially hard to hear differences of the tonality of a transient sound if not combining the tonality with vibration. The transient sound without vibration and the transient sound with –5dB are very similar when hearing/feeling sound and vibration. In the graphs one can see that the participants have rated that the transient sound without vibration and the transient sound with –5dB as equally liked while the potential customer would like the transient sound without vibration the most.

6.3 Listening room vs. SoundCar

These analyses are very interesting, because between these comparisons one can see differences between the listening room/ SoundCar. In general one can say that there are differences between the transient sounds that have vibration and between the transient sounds that has no

vibration. For the sounds without vibration the transient sound played in the listening room is rated slightly higher in the scales compared to the transient sound without vibration played in the SoundCar.

The first analysis that is made is between the transient sounds. There are several significant differences between the genders and between the groups for the transient sounds. The males have in general rated the sounds slightly higher than the females, between the analyses for the transient sounds. The only adjective where the females have rated the transient sounds higher than the males is for the adjective unpleasant. The explanation for the differences between the females and males could be due to that the females likes the transient sound less compared to the males. The most liked transient sound is the transient sound without vibration (SoundCar) and the transient sound with –5dB vibration. This result shows that vibration affects the transient sound negative and that a sound without vibration played in the SoundCar has positive effects to the transient sound. Maybe it is more comfortable with less vibration or the transient sound is perceived as less bad, maybe it was even perceived as pleasant.

The second analysis made was between the idle sounds. For the adjective powerful, there was a significant difference between the groups. Group one (started the test in the listening room) has rated the idle sounds as more powerful than group two (started the test in the SoundCar). The explanation for that could be due to that group one had heard the idle sound in the listening room and found the sounds even more powerful when performing the test in the SoundCar. In general the participants dislike the idle sounds with natural vibration and the idle sound vibration, -10dB order 93. This result is a little bit strange to the author, but out of this one can see the effect of being seated into a SoundCar instead of a listening room, the sound are more real, and maybe even less liked because of that.

The third analysis that was made was between the WOT sounds. There are significant differences between the groups for the three adjectives: tonality, desirable and reliable. For the adjective tonality, group one has rated slightly higher than group two. Group one has rated the WOT sound from the listening room and the WOT sound with +5dB vibration as being equally tonal, the group has also rated the WOT sound with natural vibration and the WOT sound without vibration as equally tonal. Group two has rated the WOT sounds completely differently; the WOT sound with natural vibration and the WOT sound with +5dB vibration as equally tonal. The reason for the large differences between the groups is very strange to the author. One explanation could be that the participants found it hard to estimate the tonality in the sounds. For the other adjectives desirable and reliable group two has rated the sounds slightly higher than group one. In general the thoughts about the sounds are similar between the groups. Out of the WOT sounds one ca see that the amount of vibration is an important factor if liking the sound, the more vibration the less liked is the WOT sounds.

The results between the listening room vs. SoundCar shows that in general the vibration affect the perception a lot and the environment is an important factor, even though one might think that that the difference is not large between the room the feeling of reality is much larger in a SoundCar.

7 Conclusion

Sound quality and perception is very individual and can be perceived as both positive and negative. A positive sound is perceived with positive reactions while negative sounds can be perceived as uncomfortable for the individual. Vibration has large affects on the sound, both positive and negative. It is very individual when a person starts to feel discomfort caused by vibration, and the differences between the individuals are quite large.

The listening test in the listening room has shown that the BTPA method is a good engineering tool for the NVH- engineers. The participants could not tell that the simulated BTPA sound were not measured for real, even though that the BTPA sounds were recorded in CD1. Even if a few participants said that they did not hear a significant difference between the BTPA sound the results from SPSS shows that there are significant differences between the sounds. One expected that there should be differences between the sounds because the structure borne sound was raised in the simulated BTPA sounds.

Out of the questionnaire one can see that there are perceptual differences between the describing adjectives and for the questions. There are especially three adjectives that comes up several times when discussing the significant differences between the genders; roughness, tonality and aggressive. The adjective roughness seems to have largest difference between the genders followed by tonality and aggressive. The conclusion out of this is that there is a difference between the genders when estimating sounds.

There are as well perceptual differences between the groups and the conclusion drawn for this is that the sound that is played might be perceived as different depending on where the listening test is performed. I.e. if looking at the evaluation between the listening room and the SoundCar there are in some occasion's differences between the sounds: idle, transient and WOT. Group one, that started the test in the listening room found the idle sounds more aggressive in the SoundCar, compared to group two that started the test in the SoundCar. For the transient sounds there are differences for the adjectives unpleasant and desirable; group one rated the transient sounds as more unpleasant than group two. The second part of the questionnaire was to answer a question about if they liked the transient sound, and for that question group two rated that they liked the transient sound more than group one. For the WOT sounds there are significant differences between the groups for the adjectives tonality, desirable and reliable. Group one has rated the adjectives desirable and reliable higher than group two for the WOT sounds. Group two has rated the WOT sounds as having a higher amount of tonality than group one.

In general the sounds without vibration is perceived as:

- Having a higher amount of tonality
- Less powerful than the sounds with vibration
- Less unpleasant compared to the sounds with vibration (SoundCar)
- To some extent less rough in the SoundCar
- Less aggressive for transient and WOT sounds played in SoundCar and more aggressive for idle sounds played in the SoundCar
- In general less attention demanding (SoundCar)
- In general less reliable (SoundCar)

The reality questions in the test showed that there are slightly differences between playing a sound with/without vibration. If the perceived result expects to be close to reality the listening test should be performed in the SoundCar. The feeling of being seated into a SoundCar with vibration is fairly convincing.

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Appendix A: Sound Quality metrics [A]

1. Sharpness
Sharpness is the high frequency components of sound and makes the sound sharp. From a level from 30 to 90 dB sharpness is increasing by a factor of two. Another factor that is affecting the sharpness is the dependence of the bandwidth, especially when the bandwidth is smaller than the critical band. If one or more tones fall into the same critical band, one cannot notice difference in the sharpness. The most important factors for sharpness:

- Spectral content (the perceived sound is calculated from the weighting of the spectral distribution)
- The center frequency of narrow-band sounds

The sensation for sharpness is acum. Definition of 1 acum: perception of sharpness, which is caused by band-pass noise at 1 kHz tone with a level of 60 dB and a bandwidth of 200 Hz.

The sharpness increase with increased center frequency for narrow-band noises. At a low center frequency it increases so much that it is almost in the same position as the critical-band rate, which have a sharpness of 1 acum. The proportionality between the sharpness and critical band is valid up to 3 kHz. For higher frequencies the sharpness increases faster and the critical band rate is not increasing any more because of a limitation.

Bandwidth, which is the other factor that is affecting sharpness, can make the sharpness decreased by adding sound at lower frequencies.

2. Fluctuation strength
The definition of fluctuation strength says that the fluctuation strength is indicating the temporal fluctuation of a sound. The unit for fluctuation strength is vacil and is perceived as fluctuation strength of a 1 kHz tone, which has a level of 60 dB, and is 100 % modulated with 4 Hz.

Fluctuation strength shows a maximum around 1 Hz for and this will lead to that sound which have 4 Hz modulation frequency have very much fluctuation strength, and it doesn't matter if one have used amplitude modulation /frequency modulation or broad-band or narrow band sound modulation. When the sound pressure increases the fluctuation strength increases.

Time variations below 20 Hz for modulation frequency are called fluctuations.

3. Roughness
Roughness is a significant sensation that is describing how "jumpy/bumpy" a sound is. A high sensation of roughness might lead to tiredness to individuals. When determining roughness there are two important parameters:

- Amplitude (degree- and frequency modulation)
- Frequency (degree- and frequency modulation)

Where maximum roughness is reached depends on the center frequency, but roughness can be achieved at other center frequencies as well. Roughness is increasing with modulation frequency to a certain point, maximum roughness, than it is decreasing. At lower frequencies the critical band is an important factor because it affects the maximal roughness, caused by temporal resolution of the hearing. The sensation of roughness is influenced by two characteristics:

- Frequency resolution (low center frequency)
- Temporal resolution (high center frequency)

Frequency modulation is in one way a worse parameter than amplitude modulation because a frequency modulation can cause a higher sensation of roughness. I.e. 6 asper can be achieved for a high frequency modulation. If the sound pressure level is increased by 40 dB the roughness will be three times as high.

If increasing modulation frequency from low to high values for a 1 kHz tone, three different sensations are involved:

- Fluctuation
- Roughness
- Three audible tones

Fluctuation is achieved for low modulation frequencies where the loudness changes slowly. The maximum for the sensation fluctuation is at 4 Hz and decreases for higher frequencies. At 15 to 70 Hz the second sensation take place, roughness, for higher modulation frequencies than 70 Hz the roughness is decreasing. The third sensation is to hear three audible tones and the sensation starts to occur at 150 Hz and it is increasing for higher modulation frequencies. Through the discussion above one can indicate that roughness is easily achieved by quick changes that are produced in the frequencies 15-300 Hz.

The unit for roughness is asper and 1 asper is the roughness of a 1 kHz tone that is 100 % modulated at a sound pressure level of 60 dB with a frequency of 70 Hz.

4. Tonality

The tonality can be defined by a function that is specifying the fraction of the different tonal components to the total loudness. Both masking effect and hearing threshold are included. The tonality includes a lot of sounds and describes tone quality out of i.e. noise. Tonality describes the relationship between the tones that are in different scales/intervals.

In tonality there are a difference when measuring a signal to see how the tonal components looks in a spectrum, one can see that there are a difference between tones and noise. The difference that one can see is that tones consist of tonal components and noise/broadband noise has no/very little tonality.

When noise and tones are together in a signal one have to use special metrics to handle the mixture of noise and tones. The two most ordinary metrics that are used are:

- Tone/noise ratio [dB]
- Prominence ratio [dB]

The definition of Tone/noise ratio is the difference between sound pressure level and noise level in critical band. The definition for prominence ratio is that there are a comparison between the sound pressure level of the signal in the critical band (where the tone is) and the total sound power level of the signal in the rest of the critical band.

5. Sensory pleasantness

Sensory pleasantness is hard to define in one word because it is a very complex sensation. The sensory pleasantness defines how/what individuals found as pleasant through physical parameters of sound and the subjective relation that the listener have to the sound. The parameters that are seamed to be non- acoustic must be ignored if possible. Several sensations is included in sensory pleasantness:

- Loudness
- Tonality
- Sharpness
- Roughness

Because of these different sensations is included in the sensory pleasantness it is very hard to see it as a single sensation. To get the single sensation of the term one must measure the dependence of the sensory pleasantness sensation in comparative values.
Through different experiments one can state that the sensory pleasantness:

- Decrease with increasing sharpness
- High pleasantness for pure tones
- Low pleasantness for band-pass noise
- Increase with tonality

The four sensations that affects the pleasantness, influence differently. Loudness is only affecting when the loudness is higher than the normal loudness that is between two persons having a conversation. Roughness and tonality does only affect little. The sharpness is the most important sensation in sensory pleasantness.
Loudness, sharpness and roughness are calculated by special procedures so it is possible to calculate the sensory pleasantness out o the values that one gets. The tonality is subjectively judged because is does not depend on loudness or critical-band rate.

Appendix B: Recording of sound

Date: week 42, 041012-041013

Vehicle: Automatic transmission I6 engine S40
Place: TT-road
Direction of the wind: East
Wind speed: 2, 5 m/s
Ground temperature: 6, 8 °C
Air temperature: 8, 7 °C

Drive cases performed:

- WOT gear: d-mode
- Constant acc 0,5m/s^2, gear one (idle-drive)
- Constant acc 1,5m/s^2, gear one
- WOT 3-gear, the automatic transmission is in lock-up mode
- "City-drive" gear: d-mode (→60 km/h, i.e. driving from a red light)

Equipment:

Figure B1 ArtemiS software

3-axial acc, seat position

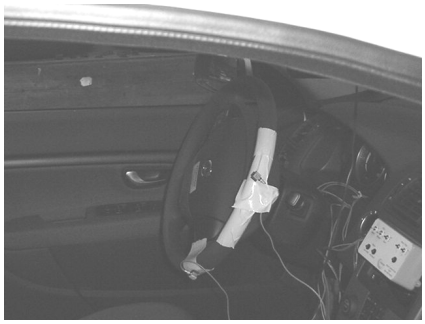


Figure B 2 3-axial acc placed on the motor block

Two 1-axial acc, steering wheel, (z-direction and y-direction)

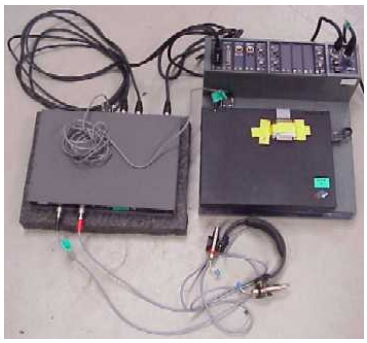


Figure B 3 BHM IV (digital binaural Head Microphone), BEQ I (Binaural Equalizer), SQlab III

ICP microphones

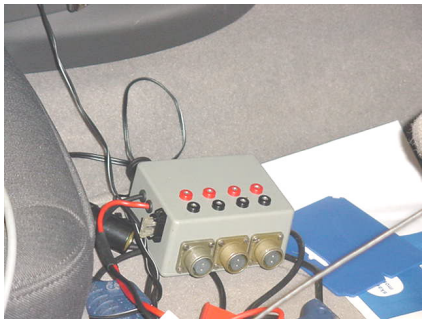


Figure B 4 DC voltage split box

Acc. indicator

Date: week 44, 041027

Vehicle: Automatic transmission I6 engine S80
Place: TT-road
Ground temperature: 9,6 °C
Air temperature: 10,6 °C

Drive cases performed:

- WOT 3 -gear
- Transient sound
- Idle D
- Idle N

Equipment:

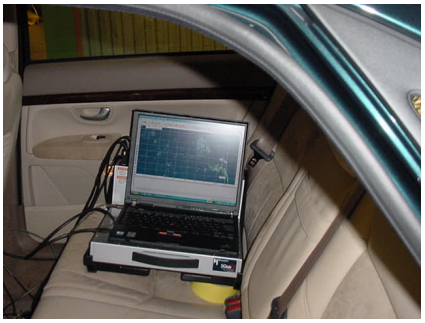
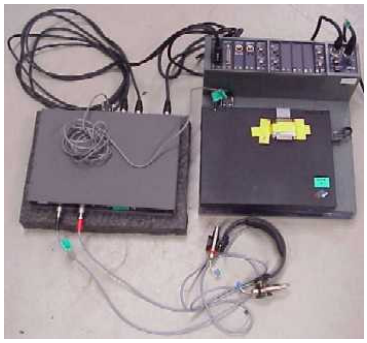


Figure B 5 Artemis software



BEQ I (Binaural EQualizer), BHM IV (digital Binaural Head Microphone), SQlab III

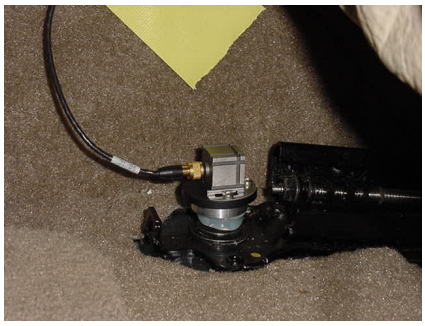


Figure B 6 3-axial acc seat position

RPM-pulse generator

Figure B 7 1-axial acc steering wheel (z-direction)

Power supply to the tachometer

Date: week 46, 041108-041112

Vehicle: Automatic transmission I6 engine S80
Place: component room. TT-road, component room

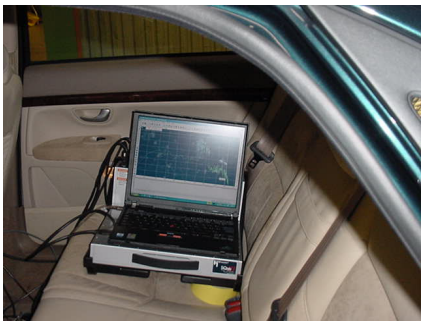
Drive cases performed:

- Transient sound
- Idle D
- Idle N

Equipment:

Figure B 8 1-axial acc steering wheel (z-direction)

Figure B 9 Tachometer (RPM)



SQlab III, Artemis Software

Figure B 10 Artificial Head

Power supply to the tachometer

Appendix C: Listening test formula

Listening room

Introduction

Hi and welcome!

You are now participating in a study where you will listen to a number of sounds. In the listening room different interior car sounds will be played individually. If you have any questions, don't hesitate to ask. Remember, there is no right or wrong when answering questions to a listening test!

During this test you will hear 12 different sounds recorded from driver's position in a VOLVO. You will hear the sounds through the headphones placed in front of you.

Each sound lasts for approximately 15 sec. You will be asked to rate the sounds in a rating scale that consists of 8 adjectives after listening to the sound. Try to think about how you feel in that very moment; avoid describing how your feelings might change over time while filling the rating scales. Do all judgments with your feelings during sound exposure in mind. There will also be a question that should be answered with help with the VCC scale (scale for subjective rating, VOLVO scale).

Your participation is confidential and anonymous. Your answers will only be statistically treated and cannot be identified among the other answers.

Instructions about the scales are described below.

On the first scale, you will estimate the sound with help of 8 adjectives. If you, for example think that the sound is very powerful, put a circle around number 8. If you think that the sound is not powerful at all, put a circle around 0.

In the second scale you will estimate how much you like the sound in a rating scale. If you like the sound a lot do a circle around number 4, if you don't like the sound at all put a circle around -4.

In the third scale you will estimate the sound with help of the VCC scale. Half points must not be used.

The final part in the questioner considers the "reality" of the sounds. In this part you will estimate the sounds with numbers.

Background information

Everything that is written down is confidential. Thank you for participating in this study.
If you are interested of the result I can send you short information when the analysing process is ready. Do you have any questions?

Sound 1

How well do you think the adjective correlates with the sound?

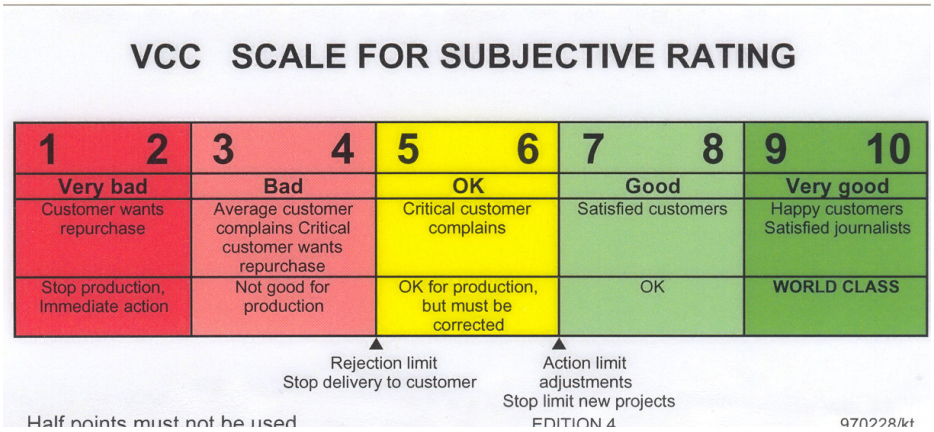
	Not at all								Very much
Powerful	0	1	2	3	4	5	6	7	8
Unpleasant	0	1	2	3	4	5	6	7	8
Rough/ Roughness	0	1	2	3	4	5	6	7	8
Attention demanding	0	1	2	3	4	5	6	7	8
Tonal/Tonality	0	1	2	3	4	5	6	7	8
Aggressive	0	1	2	3	4	5	6	7	8
Desirable	0	1	2	3	4	5	6	7	8
Reliable	0	1	2	3	4	5	6	7	8

How much did you like the sound?

Don't like at all								like a lot
-4	-3	-2	-1	0	1	2	3	4

How do you estimate the sound with help with the VCC scale?

1 2 3 4 5 6 7 8 9 10



Answer following questions considering the reality in the situation.

1. How realistic (similar to reality**)** do you think that the situation was? Mention a number between 0 and 100, where 0 means that it was not at all like the reality and 100 means that it was exactly as reality.

Mention a number: _____

2. Mention how present you felt in the situation on a scale from 0 to 100 (0=not present at all, 100=totally present)

Mention a number: _____

Sound car

Introduction

Hi and welcome!

You are now participating in a study where you will listen to a number of sounds. In the test different interior car sounds with and without vibrations will be played. If you have any questions, don't hesitate to ask. Remember, there is no right or wrong when answering questions to a listening test!

During the test you will be seated in a sound car, VOLVO S80 together with instructor.
You will be seated at driver's position and the instructor will be seated next to you and take care of the equipment. The sound car is equipped with vibrations on both steering wheel and seat. You will wear headphones during the listening test in the sound car.

Each sound will last for approximately 20 sec. You will be asked to rate the sounds in a rating scale that consists of 8 adjectives after listening to the sound. Try to think about how you feel in that very moment; avoid describing how your feelings might change over time while filling the rating scales. Do all judgments with your feelings during the sound exposure in mind. There will also be a question that should be answered with help with the VCC scale (scale for subjective rating, VOLVO scale).

Your participation is confidential and anonymous. Your answers will only be statistically treated and cannot be identified among the other answers.

Instructions about the scales are described below.

On the first scale, you will estimate the sound with help of 8 adjectives. If you, for example think that the sound is very powerful, put a circle around number 8. If you think that the sound is not powerful at all, put a circle around 0.

In the second scale you will estimate how much you like the sound in a rating scale. If you like the sound a lot do a circle around number 4, if you don't like the sound at all put a circle around -4.

In the third scale you will estimate the sound with help of the VCC scale. Half points must not be used.

The final part in the questioner considers the "reality" of the sounds. In this part you will estimate the sounds with numbers.

Background information
Everything that is written down is confidential.

Thank you for participating in this study.

If you are interested of the result I can send you short information when the analysing process is ready.

Do you have any questions?

Sound 1

How well do you think the adjective correlates with the sound?

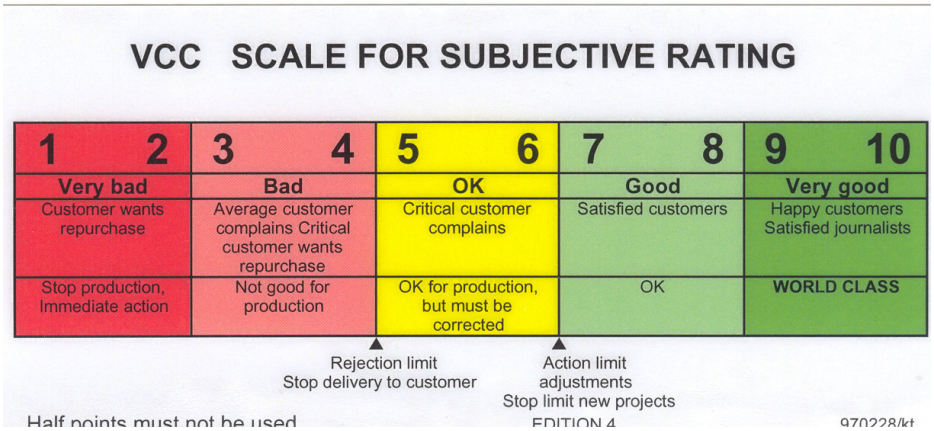
	Not at all								Very much
Powerful	0	1	2	3	4	5	6	7	8
Unpleasant	0	1	2	3	4	5	6	7	8
Rough/ Roughness	0	1	2	3	4	5	6	7	8
Attention demanding	0	1	2	3	4	5	6	7	8
Tonal/Tonality	0	1	2	3	4	5	6	7	8
Aggressive	0	1	2	3	4	5	6	7	8
Desirable	0	1	2	3	4	5	6	7	8
Reliable	0	1	2	3	4	5	6	7	8

How much did you like the sound?

Don't like at all								like a lot
-4	-3	-2	-1	0	1	2	3	4

How do you estimate the sound with help with the VCC scale?

1 2 3 4 5 6 7 8 9 10



Answer following questions considering the reality in the situation.

1. How realistic (similar to reality) do you think that the situation was? Mention a number between 0 and 100, where 0 means that it was not at all like the reality and 100 means that it was exactly as reality.

Mention a number: _____

2. Mention how convincing the feeling was to sit in a car by doing a circle around a number below. 0 means that it was not a convincing feeling at all and 10 means that it was a very convincing feeling.

Not at all convincing **very convincing**

0 1 2 3 4 5 6 7 8 9 10

3. Mention how present you felt in the situation on a scale from 0 to 100 (0=not present at all, 100=totally present)

Mention a number: _____

Background information:

Name: _____

Gender: _____

Age: _____

Thank you for participating!

Ljud 1

Hur tycker du att adjektivet stämmer överens med ljudet?

	Inte alls								**Mycket**
Kraftfullt	0	1	2	3	4	5	6	7	8
Obehagligt	0	1	2	3	4	5	6	7	8
Rått/Råhet	0	1	2	3	4	5	6	7	8
Uppmärksamhetskrävande	0	1	2	3	4	5	6	7	8
Tonalt	0	1	2	3	4	5	6	7	8
Aggressivt	0	1	2	3	4	5	6	7	8
Önskvärt	0	1	2	3	4	5	6	7	8
Driftsäkert	0	1	2	3	4	5	6	7	8

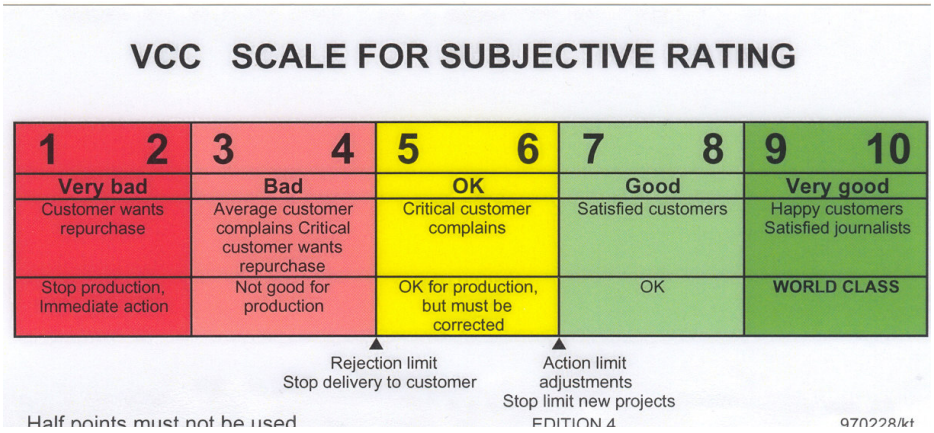
Hur mycket tycker du om ljudet?

Tycker inte alls om **Tycker mycket om**

-4 -3 -2 -1 0 1 2 3 4

Hur bedömer du ljudet med hjälp av VOLVO-skalan?

1 2 3 4 5 6 7 8 9 10



Appendix D: The Sounds

Sounds in listening room:
1. Gear 3 WOT (S40, I6)
2. Gear 3 WOT (S80, I6)
3. Idle parking (S80)
4. Idle parking -10dB, order 93 (S80)
5. Idle parking bandstop, order 95 (S80)
6. Idle sweep
7.Measured BTPA sound
8. Simulated BTPA sound, structure borne sound +2dB
9. Simulated BTPA sound, structure borne sound +6dB
10. Simulated BTPA sound, structure borne sound +4dB
11. Transient sound (V70)

Sounds in SoundCar:
1. WOT with natural vibration
2. WOT without vibration
3. WOT with vibration +5dB
4. Idle parking with natural vibration
5. Idle parking without vibration
6. Idle parking vibration –10dB order 93
7. Transient with natural vibration
8. Transient without vibration
9. Transient with vibration +5dB
10. Transient with vibration –5dB