CHALMERS

Sound sources contributing to the interior sound environment in truck cabins

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

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Göteborg, Sweden 2007

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Cover:

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Reproservice / Department of Civil and Environmental Engineering

Göteborg, Sweden 2007

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Abstract

Sound quality assessment has become a standard concept in the design in the field of vehicle acoustic performance optimization. However, unlike for passenger cars, for heavy vehicles this concept is roughly just keeping the sound pressure levels as low as possible. Nonetheless, to heavy vehicles a similar approach can be formulated as it has been done for passenger cars. With that in mind, this thesis aims to investigate the contribution of different sound sources to the interior sound environment in the truck cabin and to understand how these different sources affect users' preference and emotional reactions. Four different parameters were chosen to be studied: '*engine noise SPL*', '*broadband noise SPL*', '*presence of turbo noise*' and '*spectral slope of broadband noise*'. A listening test was performed to see the effects of those parameters to the users' preference and reactions during two different driving conditions: acceleration and constant speed driving. It was found that *'engine noise SPL'* affected users' preference and reaction during the acceleration case, while *'broadband noise SPL'* had effects during constant speed driving. Moreover, *'presence of turbo noise'* had important effects during both driving conditions. However, *'spectral slope of broadband noise'* did not have important effects.

Key words: product sound quality, sound inside truck cabins, sound sources of trucks

Acknowledgements

Primarily, I would like to thank to the supervisor of this thesis, Anders Genell, for his interest and support, his advice and his patience throughout the whole work. Next, I would like to thank Professor Mendel Kleiner for his valuable feedback and comments on the thesis.

I also would like to thank people in the Division of Applied Acoustics, whom contributed to the creation of such a friendly atmosphere, for their generosity and knowledge.

Finally, I thank my family and friends for their priceless support. I would not be where I am if it were not for their love and trust.

Contents

1 Introduction

Sound quality assessments have become a standard part of the design process in the field of vehicle acoustic performance. Therefore, in order to analyze and describe the perceptual properties of vehicle sounds, a great research effort is spent. The features of vehicle interior sound have been investigated mostly for passenger cars that are commonly used by the majority of the population. However, acoustical aspects of heavy vehicles have not been investigated thoroughly. Nevertheless, one can adapt the procedure that has been used for passenger cars for investigating the features of interior sound to heavy vehicles. In order to achieve this, one needs to know perceptually important properties of the interior sound environment of a heavy vehicle. Since a truck is a quite complex structure, there are a number of different sound sources, which contribute to the overall sound. Thus, one needs to find out the properties of these different sources so as to investigate the sound quality of a truck and improve it. With that motivation the purpose of this thesis is to:

- Investigate the contribution of different sound sources to the interior sound environment inside truck compartment.
- Point out the sources that are dominating the sound inside the cabin.
- Understand how different sources and changes in these sources effect the user's reaction to the sound and preference.

In order to fulfil these goals, a certain procedure is followed. Firstly, one needs to isolate different sources, which can be achieved by either designing a special measurement setup for recording different sources or data processing and digital filtering.

An example to the former could be the experimental setup called Wind Noise Bus designed by Volvo Trucks to record wind noise while driving. Briefly, a truck with an extended chassis, which houses the engine at the very back of it, is used. Moreover, exhaust and intake pipes are located in the far back of the truck, so while driving one can record wind and tire noise inside the cabin, without influence from the engine or powertrain (Agnesson, Hubenette 2002).

Some other sound sources like engine, turbo and fan can be isolated using digital filers. Since these sources are rotating machinery, once there is sufficient information about the technical specifications and working conditions one can isolate their tonal components using tracking filters.

After having the sources separated, next thing is to vary the properties of different sources systematically and synthesize them to have the sounds contain the selected aspects. Finally, a listening test is performed using the sounds that are synthesized in order to measure the reaction of the user to the variations in each sound source.

2 Background

2.1 Product Sound Quality

It is obvious that one needs the existence of a product in order to be able to talk about product sound quality. One can study product sound quality in three different stages: physical, auditory perception and judgment.

Physical stage means the acoustic waves emitted from the product. If we consider a truck, which is a complex structure with different sound sources, as an example, then all different components of it would contribute to the sound radiated from it. Therefore, they would also contribute to the sound quality of the truck.

The next stage, which is auditory perception, is what people hear. When the users are exposed to the sound radiated from the product, they may hear something and the consequence of this perception is called auditory event. By the use of psychoacoustics, which is the study of human perception of sound, it is possible to quantify the perceptual factors of auditory events. There are a number of different psychoacoustic measures i.e. loudness, sharpness, roughness etc. which are very functional when analyzing perceptually significant differences between sounds. However, only by knowing these measures, one cannot conclude a statement about the preference. Psychoacoustic measures are just physical properties of the sound by themselves. That fact brings us to the third stage.

It is evident that product sound quality is much dependent on a user. Therefore, the third stage is the reaction from a user to the sound of a product. However as much as it seems that it is a straightforward process like an issue of like or don't like, evaluation of product sound quality is a complicated procedure. For the reason that there are different factors, which do not depend on the sound itself but the user, influencing the process of judgment, such as user's actual cognitive, actional and emotional situation. Consequently, product sound quality is not a property of a product only, but it is rather a concept that exists when a user judges the sound of a product with respect to his/her expectations and desires in a certain situation.

When investigating psychological aspect of sound quality, Guski (1997) pointed out three approaches: (1) stimulus-response compatibility, (2) pleasantness of sounds and (3) identifiability of sound sources. Stimulus-response compatibility can be explained by suitability of a sound to a product. The main compatibility mapping between stimulus and response is the spatial compatibility, which means spatial correspondence between a stimulus and the destination of a requested movement. Another compatibility mapping, besides spatial compatibility, is error vs. command i.e. using of warning signals.

Pleasantness of sounds can be measured by using questionnaire items with appropriate response scales. Previous research showed that several physical parameters are correlated with the unpleasantness, i.e. sound pressure level, loudness, amplitude modulation, sharpness, roughness and tonality. Influence of these parameters can be investigated with varying each parameter systematically and repeating measurements.

Guski (1997) also remarked that people listening to a sound have the tendency to identify the source or, at least, they try to relate the actual sound with another sound source that they already know. One use of this behaviour might be asking people if the sound belongs to a product of a certain brand. Thus, the sound should be recognizable for the user.

In order to achieve a fine sound quality one has to take all these aspects into account, identify perceptually significant sources and find out the contribution of these sources to the identification of the product. All parts of a product should sound in place in order to give the desired impression. Consequently, one has to know what acoustical properties influence the desired impression.

The way to measure product sound quality is to ask the user what he/she thinks: perform a listening test. Therefore, in listening tests, subjects are not only the objects of the measurement, but also measuring instruments by themselves. In Figure 1, a diagram of a listener in the product sound quality assessment can be seen. One can interpret the figure as the output of this process is not just determined by the acoustic input; however it develops from a complicated relationship among expectations, mood, auditory input and non-auditory input.

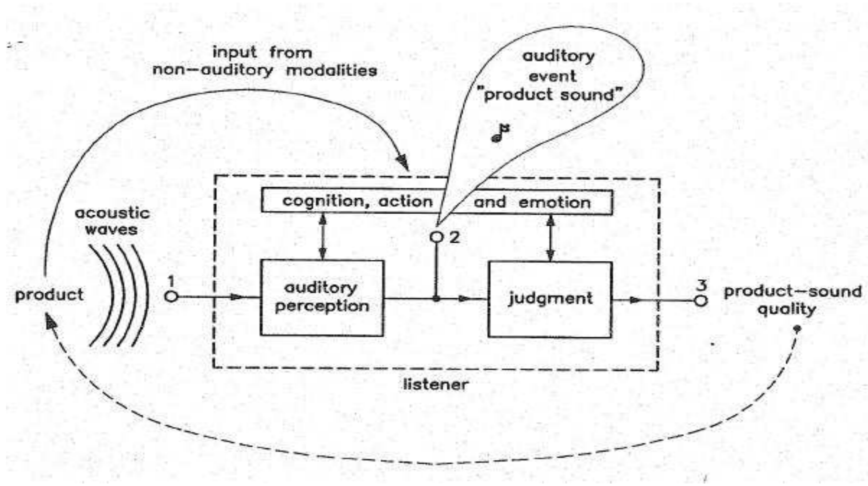


Figure 1 *Listener in the process of sound quality assessment (taken from Blauert & Jekosch 1997)*

Consequently, the concept of sound quality was put together as:

"Product sound quality is a descriptor of the adequacy of the sound attached to the product. It results from judgments upon the totality of auditory characteristics of the said sound – the judgments being performed with reference to the set of those desired features of the product which are apparent to the users in their actual cognitive, actional and emotional situation." (Blauert & Jekosch 1997)

2.2 Sound in truck cabins

Unlike passenger cars, sound quality of large vehicles has not been studied thoroughly. However, one can easily apply a similar procedure, which has been used to investigate sound quality of passenger cars, to heavy vehicles. In order to achieve that, one needs to find out how different sound sources contribute to user preference and also to the sound character of the vehicle.

The first property that can easily been seen while studying truck sound quality is domination of low frequency contents (see Figure 2). Low frequency sound is defined as sound between 20-200 Hz (see Bengtsson et al. (2004), Berglund et al. (1996)) by previous research on low frequency sound and its effects. Although, it is stated that humans are unable to hear frequencies below 20 Hz, i.e. infrasound, those frequencies may be perceived as separate pulses. Moreover, low frequencies may excite resonance frequencies of the body cavities, i.e. non-auditory perception.

It has been documented that exposure to low frequencies affects hearing system, vestibular system, balance, mental health, also causes annoyance, sleep disturbance and undue tiredness. Furthermore, it impairs task performance and cognition (see Persson Waye et al. 1997). When considering long hours of driving, these effects of low frequency noise become significant. Due to long wavelengths it is hard and not practical to attenuate low frequencies. In that case one needs to investigate the information conveyed by the low frequencies and find out a way to modify the signal without impairing the information content. One suggestion may be to balance high and low frequencies.

Figure 2 An example of a spectrum of interior sound in a truck cabin

Previous research indicate that A-weighted sound pressure levels, which is a common way to characterize noise, is not a sufficient descriptor for assessing effects of low frequency noise. Thus, for measuring effects of noise with significant low frequency content, such as a truck, one needs to perform a listening test.

Secondly, inside a truck cabin there is a complex sound environment. In a complex sound environment some properties of the sound draw attention. If those properties do not carry useful information to the driver then they represent noise and cause disturbance and annoyance. Furthermore, some other properties of the sound may cause annoyance even if they convey crucial information. Therefore, one does not only need to get rid of unwanted sounds if they are perceptually significant, but also alter other properties of the sound to reduce annoyance and unpleasantness. In order to be able to achieve that and obtain a good sound quality inside a truck cabin, these different sources needs to be investigated thoroughly, and their contribution to the user preference needs to be identified, which is the aim of this thesis.

3 Measurements

3.1 Hällered

A set of measurements was done in test tracks, which are owned by Volvo Group, in Hällered. Truck used for measuring the sound was an FH 16 model Volvo truck. Measurements were done using Head Acoustics HMSIII artificial head and SQLabII. Sound inside the cabin was recorded binaurally on the passenger seat of the truck for acceleration and constant speed driving conditions. For acceleration case, sound was recorded during an rpm sweep between 990-1650 rpm, at 3rd gear. For condition of constant speed, sound inside the cabin was recorded during speed of 85km/h. Apart from the sound inside the cabin,

- signals from turbo and fan
- rpm signal from the crankshaft of the engine during both driving conditions

were recorded.

3.2 Noiselab

Second set of measurements was carried out in a semi-anechoic chamber in Noiselab at Volvo Trucks. An FH 18 Volvo truck was used for the measurements, which were done using Head Acoustics artificial head. As it can be seen in the Picture 1, noise inside the cabin was recorded binaurally on the driver's seat for low idling condition (575 rpm).

Picture 1 Position of the artificial head during measurements in semi-anechoic room at Volvo Noiselab

Moreover, sound from exhaust outlet and intake was recorded outside separately, in order to see the contribution of those sources to the sound environment inside the cabin. Intake noise was recorded by placing a microphone as close as the grid at the opening (see Picture 2). Measuring the exhaust noise was carried out, by placing a microphone at the same height with and 1.5m away from the exhaust outlet. Also it was placed off centre so as to avoid turbulence effect.

Picture 2 Microphone positions during recording intake and exhaust noises

3.3 Previous measurements

Furthermore, because of practical purposes some of the previous measurements were supplied. Among those measurements, there were binaural recordings done inside the cabin for different driving conditions such as full load acceleration (rpm sweep between 990-2100 rpm), constant speed (at 85km/h), low idle (575 rpm). Also there were recordings of wind and tire noise for different driving conditions, which were carried out using Wind Noise Bus.

4 Data processing

After measurements had been done, a number of filters were applied to the data in order to isolate different sources. To be able to isolate noise from any rotating machinery such as engine, turbo etc., one needs to know the specifications of the machine and also its rpm signal while working. With that information one can apply a tracking filter that follows the rpm and filter the relevant orders of the engine and turbo rpm.

4.1 Engine noise

During all the measurements, rpm signal from the crankshaft of the engine was recorded, which gives the opportunity to filter out and isolate the tonal contribution of the engine to the sound environment inside the cabin. The engine under study is a six cylinder Volvo engine and it has two firings per cycle. In the light of that information one can identify which orders are dominant and noticeable. In this case the most dominant order is the third order.

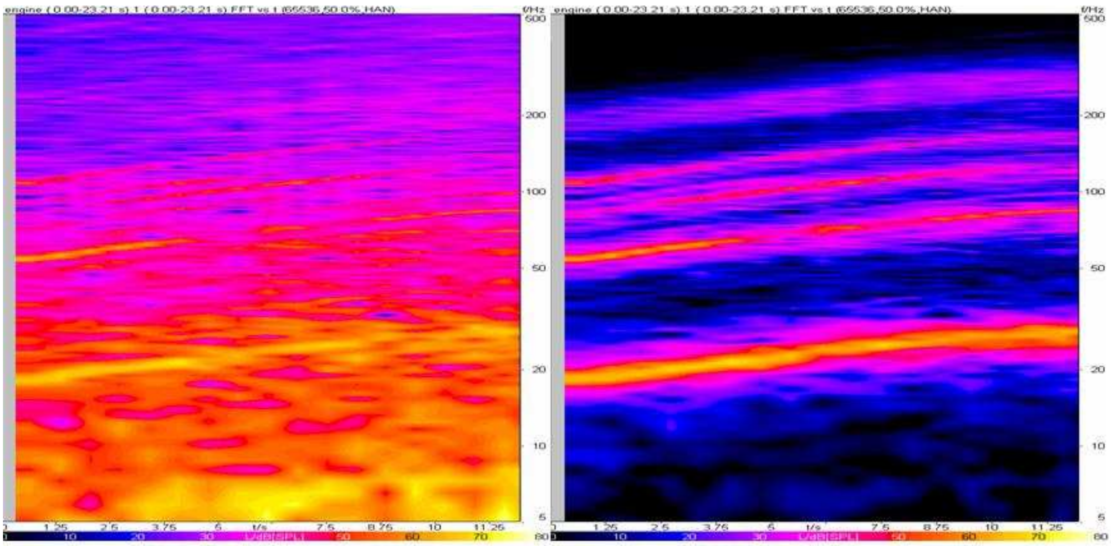


Figure 3 Isolating the engine noise (on the right) from the overall noise recorded in the cab (on the left)

Consequently, there is enough information to filter relevant orders. Filters were constructed and applied using the Advanced Filtering Module in ArtemiS software. In Figure 3, there is an example of filtering engine noise. The plot on the left side is the overall sound recorded inside the cabin, where the plot on the right shows a number of engine orders filtered from the original sound using a filter created from the rpm signal of the crankshaft of the engine while running. The most noticeable order in the figure is the third then 4.5 and 6^{th}. Above those some higher orders, which seemed noticeable during the analysis, are filtered.

4.2 Turbo noise

While filtering turbo sound a similar approach can be applied that was done for engine. However, one can isolate turbo noise easier than engine noise since turbo emits much higher frequencies (see Figure 4). Also there is no other sound around those frequencies. Therefore, one may even apply a high pass filter to isolate turbo noise. Nevertheless, since this may introduce noise, in order to isolate sound generated by turbo rpm signal of turbo was used, which was constructed digitally from the original recording using ArtemiS software. After that a filter was created using the rpm signal so as to filter and isolate the turbo noise.

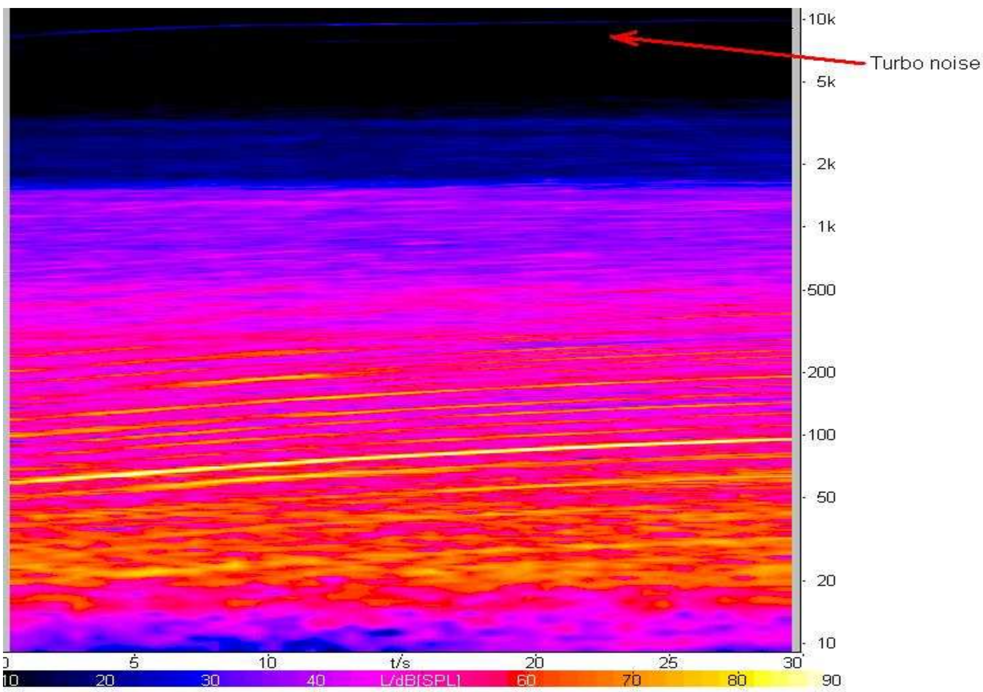


Figure 4 Turbo noise

4.3 Wind noise

It is obvious that isolating wind noise is not possible using the same way that was used for any rotating machinery since it is a broadband noise. However, wind noise can be recorded using a different experimental setup. The test rig of Volvo, which is used for recording wind noise in trucks, is called the Wind Noise Bus (Agnesson, Hubenette (2002)). The WNB is basically a truck that has an extended chassis, which houses the encapsulated engine in the very back of it. Also, intake and exhaust pipes are located in the back of the chassis. Therefore, by this design noise from these sources are significantly lowered while driving. However, because of practical issues, WNB could not be used during the thesis.

4.4 Fan Noise

Noise from fans has different properties than engine and turbo, even though the fan itself can be seen as rotating machinery. Discrete tonal components at the blade passing frequency and its harmonics can be filtered and isolated with the same procedure that was used to isolate engine noise. However, the problematic part to isolate is the aerodynamic broadband noise, which is caused by flow separation and turbulence and is continuously distributed over the frequency range of 100 Hz to 10 kHz.

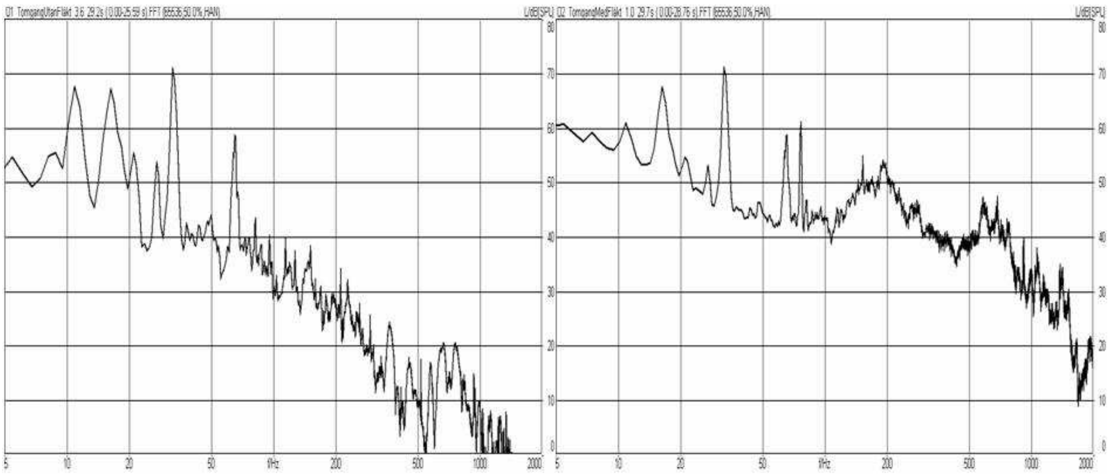


Figure 5 Noise inside the cab during low-idle with (right) and without (left) the fan loading.

Figure 5 shows the characteristics of the fan noise. The plot on the left side is the spectrum of the noise inside the cab during low idling without the fan loading, where the plot on the right shows the spectrum of the noise at the same conditions but the fan loading. On these measurements fan was controlled digitally, so that in the first measurement fan did not work. The sound character of the fan can easily be seen. The peak around 70Hz is visible in the plot on the right which was resulted from the blade passing frequency of the fan. Moreover, the broadband characteristic of the aerodynamic noise is obvious. These properties of the fan make it difficult to isolate sound generated from it.

4.5 Exhaust and intake noise

While investigating the noise emitted from the exhaust system, one can see that it has different properties that makes it complex (see Figure 6). First of all, gas-jet engine noise, which is also called aerodynamic noise, makes it difficult to isolate. While running, outside the exhaust outlet complex radiating sources are formed. Near the exhaust outlet in the mixing shear region high frequency noise is generated, whereas, lower frequency noise is generated downstream in the region of large scale turbulence. Thus, aerodynamic noise is generally broadband. Moreover, every time the exhaust valves open a pulsating noise is produced. This pulsating noise results from the specifications of the engine and is in the same frequency region of engine noise. Therefore, because of its properties, it is complicated to isolate the exhaust noise using digital filtering. In order to separate the exhaust noise from the others one might need to design a special experimental setup.

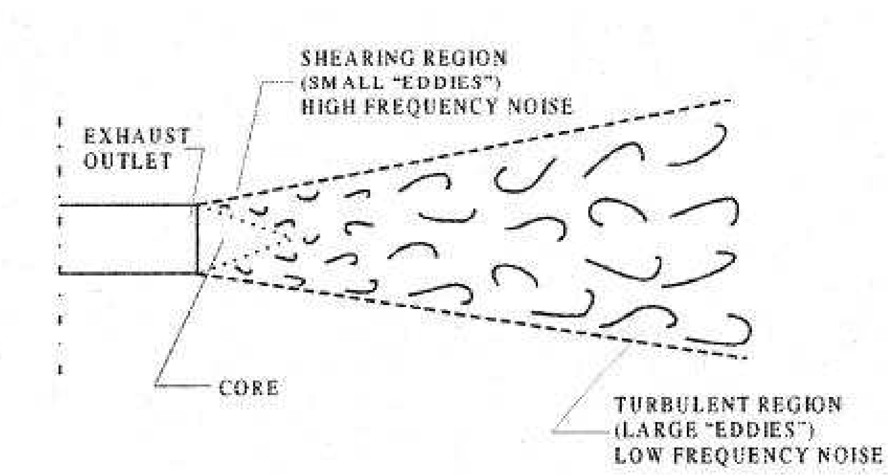


Figure 6 Properties of exhaust noise (taken from Agnesson, Hubenette (2002))

Noise generated by air intake on top of the cabin, which is another difficult source to isolate from others, is basically transferred inside the cabin both airborne and structure-borne. During air intake through the pipe which is at the backside of the cabin, vibrations in the pipe excite the back wall of the cabin which causes structure-borne noise. In addition, due to the flow of air outside the intake opening, aerodynamic noise occurs and part of it is transferred inside the cabin. Thus, these properties of intake noise makes it time consuming to separate from the overall noise inside the cabin.

4.6 Selection of parameters and preparation of tracks

For practical issues not all of the sources could be used for the project. Consequently, three different noises were taken to be studied: *"engine noise"*, *"turbo noise"* and *"broadband noise"*. Engine noise covers a number of dominant orders of the rotational frequency of the crankshaft in the engine up to 500 Hz. Turbo noise covers the tonal high frequency noise generated by the turbo, which is around 7 kHz. Finally, broadband noise is basically what is left after removing engine and turbo noises. Thus it covers aerodynamic noises including wind noise and other noises generated by different sources. In Appendix A, one can see the spectra of these different noise sources that were taken into account.

While preparing the tracks for the listening test, four parameters were taken into account and altered systematically: sound pressure level of engine noise (original, +3dB), presence of turbo noise, sound pressure level of broadband noise (original, +3dB) and spectral slope of broadband noise (original slope of -7.5 dB/oct and an altered slope of -5.5 dB/oct). Spectral slope of broadband noise was decreased by 2 dB/oct above 500 Hz. This was done to study the effect when one balances out low frequencies, which occur in the truck, with increased high frequency content.

Table 1 Alterations of different parameters under investigation

	Original	Alteration
Engine SPL	Original level	Increased by 3dB
Broadband noise SPL	Original level	Increased by 3dB
Spectral slope	Original slope	Decreased by 2dB/oct above 500 Hz
Turbo	Turbo noise on	Turbo noise off

Table 1 shows the alteration of SPLs of engine and broadband noise, including the alteration of the spectral slope. For every combination, two tracks were created, one of which contains turbo noise. With all these settings, 16 different tracks were synthesized for each driving conditions, i.e. acceleration and constant speed driving conditions. Thus, in total 32 different sounds were presented to participants. Once all the tracks are ready, level equalization was made in order to avoid the effect of loudness during the listening test.

5 Listening test

5.1 Test setup and equalization

The listening test took place in the Sound Quality Lab in the Division of Applied Acoustics, Chalmers University of Technology. This setup was used to give the realistic environment of a truck to the participants. The room used for the test is a semi anechoic room, which houses a demo of a truck cabin. In order to be able to reproduce low enough frequencies a custom built subwoofer was used. The subwoofer is an array of 15-inch woofers in a 4 by 4 matrix, which was built in an alcove in the semi anechoic room.

During the test the signals were fed to a Behringer Ultradrive Pro DCX2496 dsp. From the dsp low frequencies, i.e. below 75 Hz, were fed to the custom subwoofer through an amplifier. Frequencies above 75 Hz were fed to a pair of AKG K1000 headphones after being amplified. AKG K1000 headphones, which are high end headphones, do not interfere with the lower frequencies reproduced by the subwoofer. In that way it was tried to create the impression of a real truck to the participants during the test.

Picture 3 Listening test setup: demo of a truck cabin and custom built subwoofer

In such a test setup one needs to equalize the response of the whole setup and obtain a flat frequency response. Equalization was done in three steps. First, only the frequency response of the custom subwoofer was equalized so as to diminish room effects on the response and to get a fairly flat response. An

MLS sequence was used as an input signal and the response was recorded at the listening position. Then, the response was altered using the graphic equalizer of the dsp.

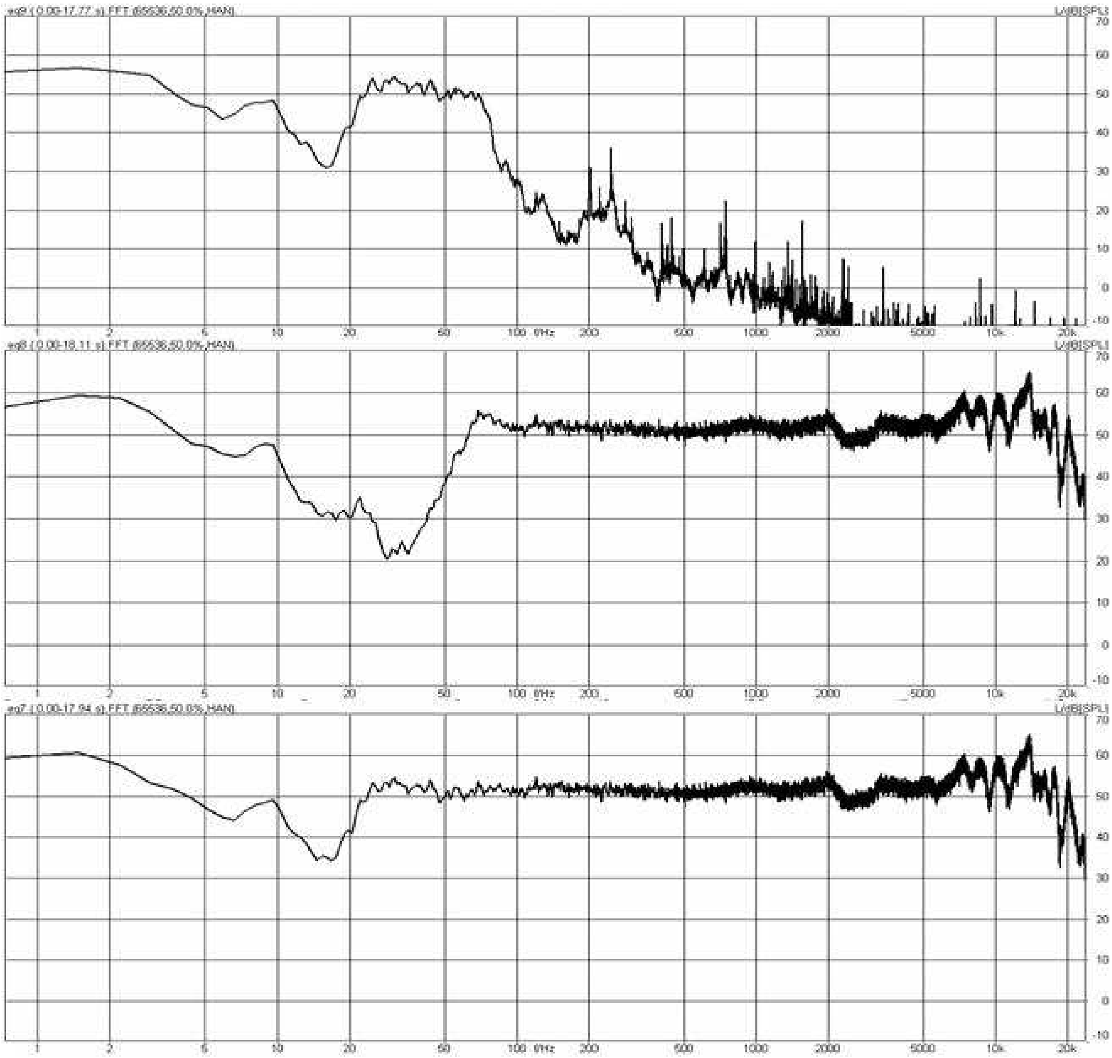


Figure 7 Frequency responses of custom subwoofer (top), headphones (middle) and both together (bottom) after equalization.

Second step was to check the response of the headphones by the same procedure. White noise was fed to the system and the response was recorded at the listening position using the artificial head.

Finally, the levels of high and low frequencies were equalized. In order to achieve this, white noise was used as input signal and the combined response was recorded at the listening position using Head Acoustics artificial head. The combined response was investigated and then the levels of high and low frequencies were equalized so as to obtain a frequency response as flat as possible. In Figure 7, one can see frequency responses of subwoofer, headphones and the combine frequency response of both. It can be seen that combined response is fairly flat between 30 to 2000 Hz, it varies within 5 dB.

5.2 Listening test

The listening test took approximately 45 minutes for each participant and they were compensated in the end of the test. Before starting the test, audiograms of each participant were measured so as to screen for normal hearing levels. None of the participants were excluded because of inadequacy of their hearing.

5.2.1 Participants

In total 34 people participated in the test. Among those 34 participants 18 of them were professional truck drivers whose ages varied in between 26 to 62 and 16 of them were students (9 females) whose ages varied in between 22 and 33.

5.2.2 Tracks

In order to avoid tiredness, tracks were divided into two different groups. Since the effects of turbo noise have been previously established, two groups were formed by tracks containing turbo sound and tracks not containing turbo sound. In other words, turbo noise was defined as a between subjects factor. The presenting order of the tracks were randomized and reversed so as to avoid learning effects.

5.2.3 Questions

During the test, participants were asked to judge the different truck sounds according to the questionnaire, which was prepared in Swedish since all the participants were Swedish (see Appendix B). First, they were asked to rate how they were feeling when they heard each sound using the nine-point Self Assessment Mannequin (SAM) scales, ranging from pleasant to unpleasant and from activated to not activated respectively.

Furthermore, they were asked to rate the characteristics of each sound according to a number of unipolar adjective scales. These adjectives were annoying, howling, noisy, tiring and rumbling. They were also asked to what degree they thought that the sound belonged to a powerful truck, to a truck of high quality, to what degree they thought the sound suited a truck and how well they could hear how the engine works. Below is the list of questions in the same order as in the test.

- How annoying is the sound?
- How powerful do you think the truck is?
- How much do you think that this is a truck of high quality?
- How howling is the sound?
- How noisy is the sound?
- How much do you think that the sound suits to a truck?
- How tiring is the sound?
- How rumbling is the sound?
- How well can you hear how the engine works?

For every question, they were asked to pick a number between 0 and 9, representing 'not at all' to 'very much' respectively.

6 Results

6.1 Emotional reactions

For each scale a series of ANOVAs were made to see the effect of the parameters that had been under investigation. The main effects can be seen in Appendix C. The only significant effect was found was the decrease in valence caused by increasing broadband noise SPL (F=5.356, p<0.05).

Table 2 F and p values for engine SPL change in acceleration (left) and for broadband noise SPL change in constant speed (right)

Acceleration		
	Engine SPL	
	F value	Sig.
Valence	.606	.443
Activation	**6.164**	**.020**

Constant Speed		
	Broadband Noise SPL	
	F value	Sig.
Valence	**7.773**	**.010**
Activation	.094	.762

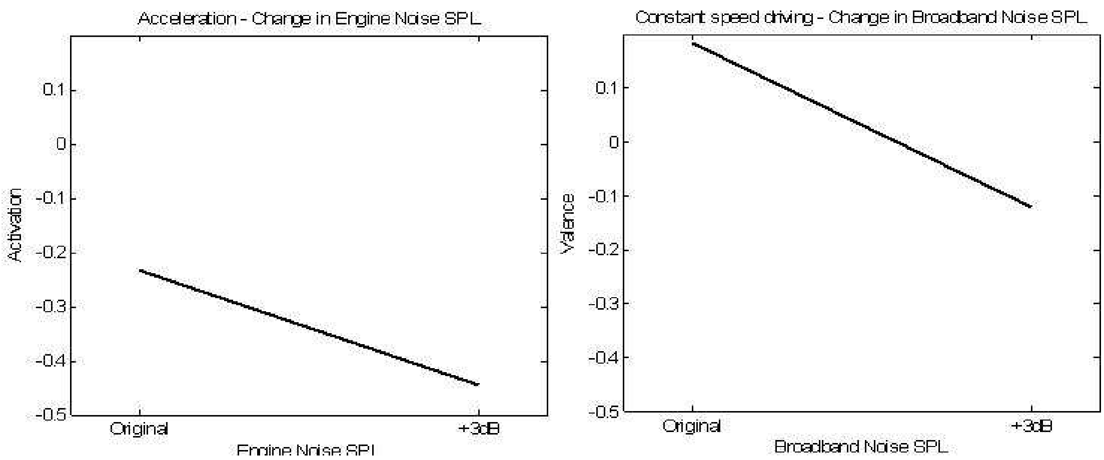


Figure 8 Effects of engine SPL on activation during acceleration (left) and broadband noise SPL on valence during constant speed (right)

Lack of significance may be a result of analyzing all effects together. One can find more significant results by looking into interactions. For instance, when the two driving conditions were analyzed separately, it was found that engine noise SPL decreased activation during acceleration whereas broadband noise SPL decreased valence while driving at constant speed (see Table 2 and Figure 8).

Table 3 *F and p values for broadband noise change in constant speed for the two participant groups, students on right and drivers on left*

Constant Speed – Students		
	Broadband Noise SPL	
	F value	Sig.
Valence	**3.948**	**.070**
Activation	.925	.355

Constant Speed – Truck Drivers		
	Broadband Noise SPL	
	F value	Sig.
Valence	**3.582**	**.078**
Activation	**4.407**	**.056**

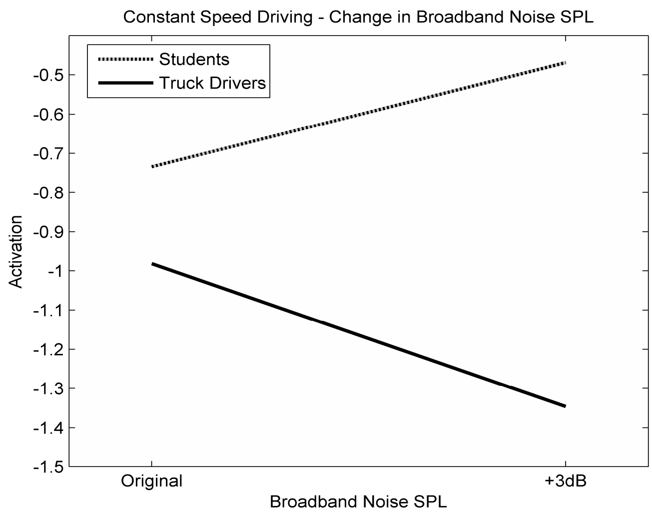


Figure 9 *Effect of increasing broadband noise SPL on activation during constant speed driving (dashed line for students, solid line for drivers)*

Another significant result was found when interactions between different participant groups were investigated, i.e. students and truck drivers (Table 3). Both students and truck drivers agreed on the negative effect of increasing broadband noise level on valence during constant speed driving. However, unlike for students, for truck drivers increasing broadband noise level during constant speed decreased activation as well (see Figure 9).

For further investigation of interactions between different parameters, the tracks including turbo noise were separated from the ones that did not. It was found that during acceleration, increasing the engine noise level while there was turbo noise present showed a tendency of decreasing activation ($F=4.464$, $p=0.056$). The effect was less significant with turbo noise removed (see Table 4).

Table 4 F and p values for engine SPL change during acceleration while the turbo is on (left) and off (right)

Acceleration – Turbo on		
	Engine SPL	
	F value	**Sig.**
Valence	.018	.894
Activation	**4.464**	**.056**

Acceleration – Turbo off		
	Engine SPL	
	F value	**Sig.**
Valence	.907	.356
Activation	2.690	.123

A similar effect was caused by broadband noise level during constant speed (see Table 5). Increasing broadband noise level decreased valence during constant speed once turbo noise was removed ($F=6.174$, $p<0.05$).

Table 5 F and p values for broadband noise SPL change during constant speed while the turbo is on (left) and off (right)

Constant Speed – Turbo on		
	Broadband Noise SPL	
	F value	**Sig.**
Valence	2.257	.159
Activation	.164	.692

Constant Speed – Turbo off		
	Broadband Noise SPL	
	F value	**Sig.**
Valence	**6.174**	**.025**
Activation	.006	.938

Table 6 *F and p values for different participant groups during constant speed while the turbo is on (left) and off (right)*

Constant Speed – Turbo on		
	Drivers vs. Students	
	F value	**Sig.**
Valence	.020	.889
Activation	.042	.840

Constant Speed – Turbo off		
	Drivers vs. Students	
	F value	**Sig.**
Valence	.200	.661
Activation	**5.606**	**.034**

Moreover, there seems to be one more significant difference between the two participant groups, which can be seen in Table 6 and Figure 10. During constant speed driving, there was no significant difference found between students and truck drivers, while turbo noise was present. Nonetheless, between the two groups a significant result appeared, when turbo noise was removed. Truck drivers were then much less activated than students were ($F=5.606$, $p<0.05$).

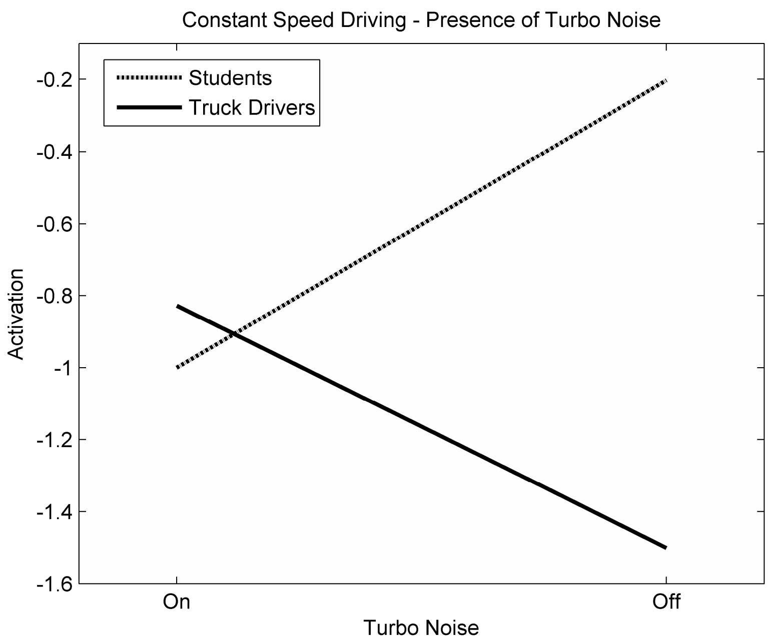


Figure 10 *Difference between students and truck drivers during constant speed driving caused by the presence of turbo noise (truck drivers represented by the solid line)*

6.2 Adjectives

The results of the ANOVAs for each adjective are documented in main effects table in Appendix C, which shows F-values and significance levels for the main effects of the different parameters. It was found that increasing engine noise level caused an increase on "rumble" ($F=7.199$, $p<0.05$) and ability of hearing how engine was working ($F=4.619$, $p<0.05$). On the other hand increasing broadband noise level caused a decrease on "rumble" ($F=3.961$, $p=0.056$) and ability to hear how engine was working ($F=5.269$, $p<0.05$), as could be expected. Decreasing spectral slope decreased "rumble" significantly ($F=14.980$, $p<0.05$) and also tended to decrease tiredness. Another expected result was the relation between turbo noise and the adjective "howling". Since turbo emits a high frequency sound around 7 kHz, it is no surprise that its presence caused a dramatic increase on "howling" scale ($F=44.503$, $p<0.01$). Presence of turbo noise also tended to decrease the perceived suitability of the sound to a truck.

For the two different driving cases, it was found that the acceleration case was rated as more suitable ($F=5.428$, $p<0.05$) and less tiring ($F=9.251$, $p<0.05$) than constant speed driving. Moreover, the participants rated it easier to hear how the engine was working ($F=14.525$, $p<0.005$) for the acceleration case, and the acceleration sounds tended to be perceived as belonging to a truck of higher quality ($F=2.963$, $p=0.097$). Finally, one can see truck drivers tended to hear the engine work better than students ($F=3.631$, $p=0.067$), which is no surprise at all.

Apart from these main effects, important results can be found by investigating different interactions. For instance, it was mentioned above that increasing engine SPL caused "rumble" to increase as well as made it easier to hear how the engine was works. However, after investigating interactions, one can point out that during acceleration, increasing engine SPL had a significant effect on "rumble" ($F=13.955$, $p<0.01$) but not on hearing how the engine was working, while there was turbo noise present (see Table 7 and Figure 11). Once turbo noise was removed during acceleration, while the effect of engine SPL on "rumble" decreased, its effect on hearing how the engine was working increased significantly ($F=4.989$, $p<0.05$).

Table 7 F and p values for engine SPL change on 'rumble' and 'hearing engine' during acceleration while turbo is on (left) and off (right)

Acceleration – Turbo on		
	Engine SPL	
	F value	Sig.
Rumbling	**13.955**	**.002**
Engine	.023	.881

Acceleration – Turbo off		
	Engine SPL	
	F value	Sig.
Rumbling	3.221	.093
Engine	**4.989**	**.041**

Moreover, during acceleration, increasing engine SPL increased the perceived powerfulness significantly when turbo noise was not present (F=11.413, p<0.01) (see Figure 11). Both students and truck drivers seemed to have agreed on that effect. However, students and drivers disagreed on the influence of engine SPL on annoyance and quality during acceleration.

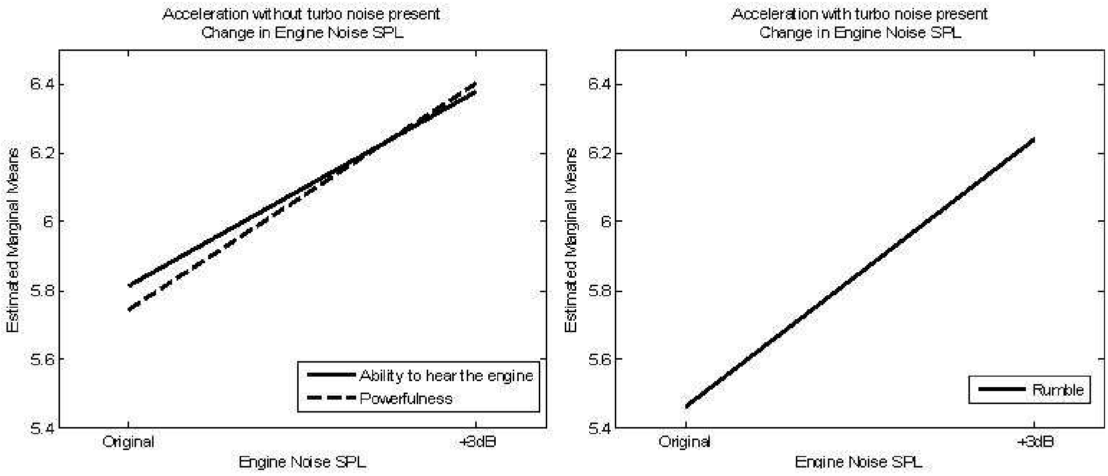


Figure 11 Effect of increasing Engine SPL on 'rumble', 'hearing engine' and 'powerfulness' during acceleration with respect to the presence of Turbo Noise

Moreover as can be seen in Figure 12, during acceleration students tended to think that increasing engine SPL increased quality but did not think it affected annoyance. On the other hand drivers seemed to be annoyed by the increase of the engine SPL, but they thought that quality was not affected (see Table 8).

Table 8 *F and p values for engine SPL change on 'annoyance' and 'quality' for different participant groups during acceleration, students on left and drivers on right*

Acceleration – Students		
	Engine SPL	
	F value	Sig.
Annoying	.002	.967
Quality	**3.250**	**.095**

Acceleration – Drivers		
	Engine SPL	
	F value	Sig.
Annoying	**3.843**	**.069**
Quality	.143	.710

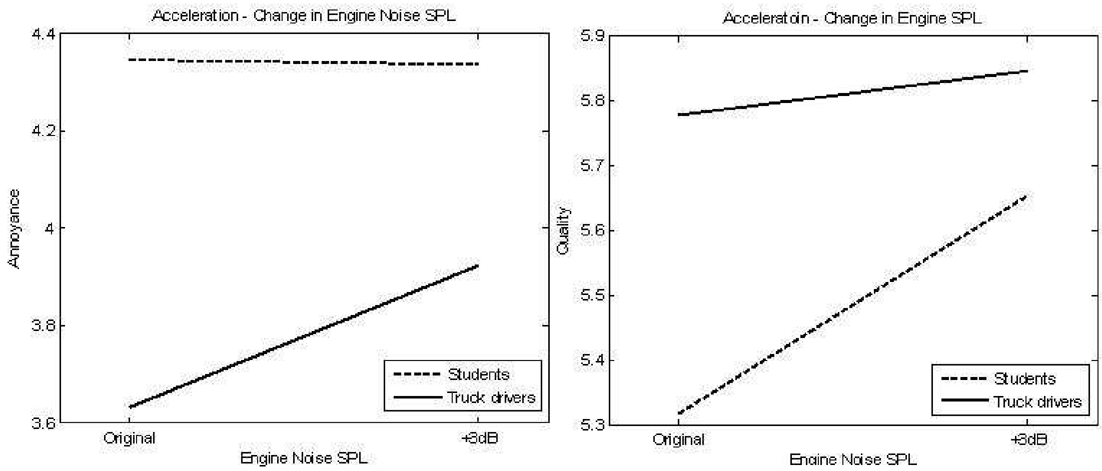


Figure 12 *Effect of Engine SPL change on 'annoyance' and 'quality' for different participant groups*

When one examines the effects of increasing broadband noise SPL, one sees that it decreased "rumble" and ability to hear how the engine was working. However, this effect, which can be seen in Figure 13 (right side) was found only when turbo noise was removed during constant speed driving ($F=10.227$, $p<0.01$ for rumbling, $F=22.067$, $p<0.01$ for hearing the engine). Some negative effects were also found for this situation. For instance as documented in Figure 13 (left side), it decreased powerfulness ($F=9.222$, $p<0.01$) and suitability ($F=8.242$, $p<0.05$) also it tended to increase annoyance ($F=3.412$, $p=0.85$).

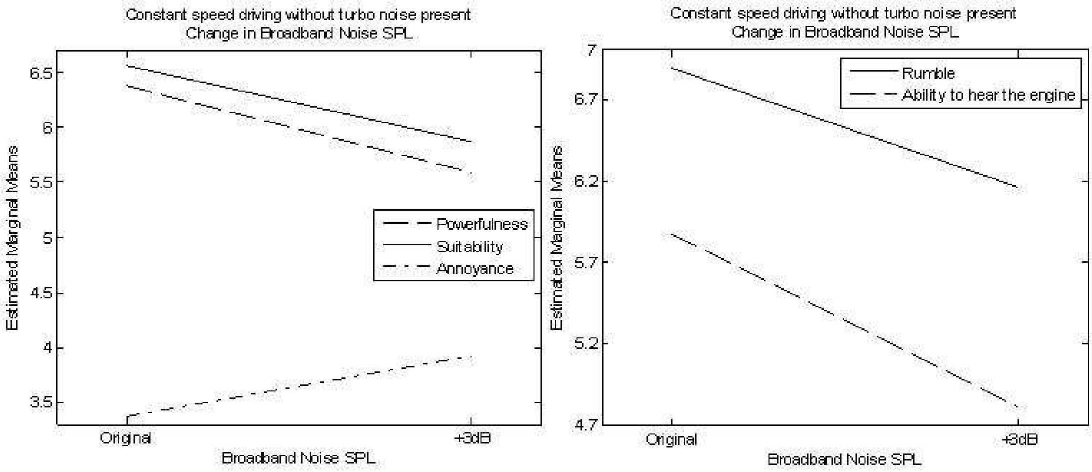


Figure 13 Effect of Broadband Noise SPL change on different adjectives while Turbo Noise was not present during constant speed driving

Furthermore, for acceleration with turbo noise present, increasing broadband noise SPL had positive effects on quality (F=25.022, p<0.01), powerfulness (F=18.390, p<0.01) and suitability (F=12.512, p<0.01), while decreasing annoyance (F=4.743, p>0.05) (see Figure 14 – right side). With turbo noise removed these positive effects disappeared. Instead, as can be seen in Figure 14 (left side), increasing broadband noise SPL had a tendency of having negative effects on quality (F=4.116, p=0.061) and suitability (F=3.340, p=0.089).

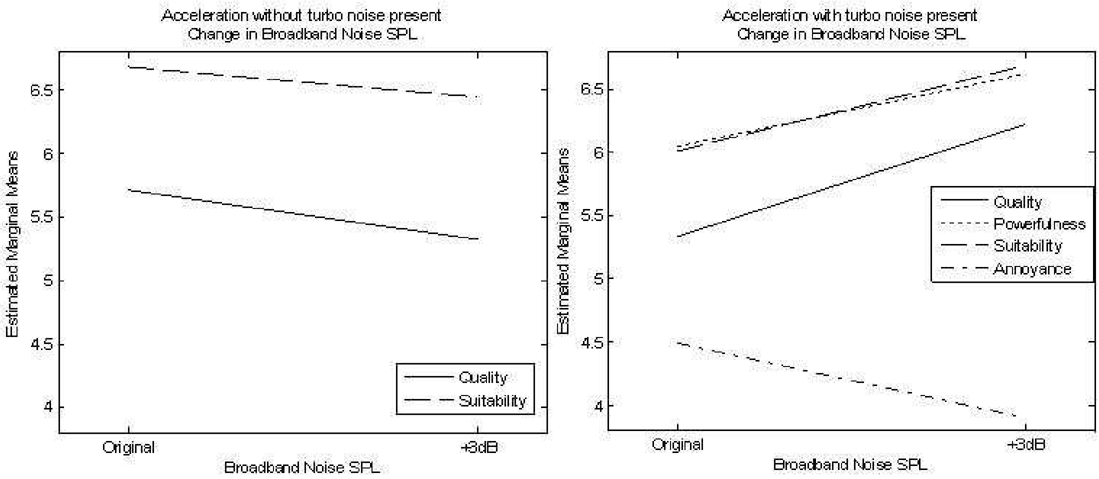


Figure 14 Effect of Broadband Noise SPL change on several adjectives during acceleration with respect to presence of turbo

Finally, one interesting result found while investigating the effects of broadband noise was that during constant speed driving, increasing broadband noise caused a decrease on the adjective "howling" (F=11.831, p<0.01) while there was turbo noise present. However, once turbo noise was removed increasing broadband noise started having the opposite effect on the adjective "howling" (F=8.194, p<0.05), i.e. increasing it (see Table 9).

Table 9 *F and p values for broadband noise SPL change on 'howling' during constant speed driving, while turbo is on (left) and off (right)*

Constant Speed – Turbo on		
	Broadband Noise SPL	
	F value	Sig.
Howling	**11.831**	**.004**

Constant Speed – Turbo off		
	Broadband Noise SPL	
	F value	Sig.
Howling	**8.194**	**.012**

Decreasing the spectral slope of the "*broadband noise*" did not have many significant effects. Mainly, it decreased "rumble" for the sounds that contained turbo noise, regardless of driving condition (F=22.267, p<0.001 for acceleration, F=8.089, p<0.05 for constant speed driving). Also it decreased the ability of hearing the engine for the acceleration case when there was no turbo noise present (F=4.625, p<0.05). Finally, when looking at the main effects table, one can say that there was a general tendency that balancing the spectral slope decreased tiredness (F=3.281, p=0.081).

Most prominent effect of turbo noise was on the adjective "howling". Regardless of driving condition or participant group, removing turbo noise caused a dramatic decrease on "howling" (F=20.419, p<0.001 for acceleration, F=53.884, p<0.001 for constant speed driving, F=24.029, p<0.001 for truck drivers, F=20.324, p<0.001 for students). Also removing turbo noise seemed to increase "suitability" for constant speed driving (F=4.215, p<0.05).

When different interactions were investigated, it was found that for hearing how engine works presence of turbo noise had some effects. During acceleration once turbo noise was removed, increasing engine SPL caused an increase in the ability of hearing how the engine was working (F=4.989, p<0.05), on the other hand balancing the spectral slope started causing a decrease on it (F=4.625, p<0.05). Also when there was no turbo noise present during the acceleration case, difference between the two participant groups became significant for hearing how the engine was working, i.e. students were much worse than drivers (F=4.712, p<0.05).

To sum it up, when differences between two driving cases were investigated, as it was said before, it was found that acceleration sounds were more suitable and less tiring than constant speed sounds. Also it was easier to understand how engine was working and it perceived as a truck of higher quality, during acceleration. Moreover, it seems that for acceleration engine SPL caused more significant differences than it did during constant speed driving, i.e. powerfulness, rumble, hearing engine. On the other hand, broadband noise SPL seems to cause more significant differences in constant speed driving than it did during acceleration, i.e. powerfulness, suitability, rumble, ability to hear engine. Finally, presence of turbo noise during constant speed driving reduced suitability; while on the other hand, it had no significant effect on suitability during acceleration. However, as much as presence of turbo noise did not cause many significant differences, it was found that presence of turbo noise affected the changes caused by the other parameters. For instance, as mentioned before, positive effects caused by the increase in broadband noise all disappeared once turbo noise was removed during acceleration case.

7 Discussion

7.1 Emotional reactions

As we have seen in the results chapter, increase in engine noise SPL caused significant effects during acceleration case. On the other hand, during constant speed driving, increase in broadband noise SPL became more significant than in engine noise SPL. This can be explained by the fact that during acceleration engine noise is a salient part of the sound environment inside the cabin. Therefore change of it would cause significant differences. However, during constant speed driving, since engine noise is more or less constant over time other properties of the sound become more prominent.

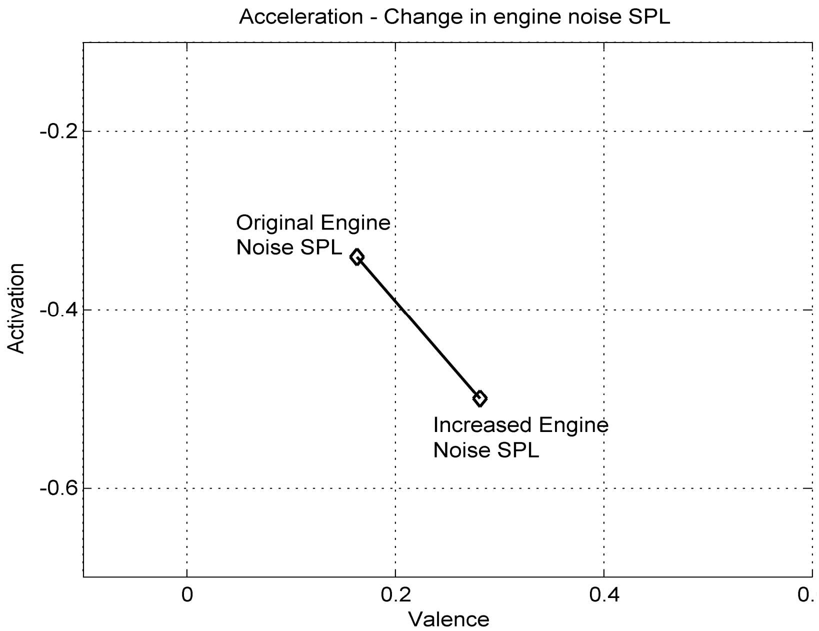


Figure 15 Effect of increasing engine SPL on the affection scales during acceleration

Figure 15 and 16 show the change caused by the increase in engine noise SPL during acceleration on the affection scales, where horizontal axis is valence and vertical axis is activation. Figure 15 and 16 show the decrease in activation caused by increasing engine noise SPL, which can be interpreted as a positive effect. Previous research (see Kahneman (1973)) illustrate that while carrying out a complicated task, in order to obtain optimum performance the activation level should be lower, i.e. *the arousal theory* (see Figure 17). Therefore, by increasing engine noise SPL, one might be able to optimize task performance of the driver, since acceleration can represent a more complicated driving situation than constant speed driving.

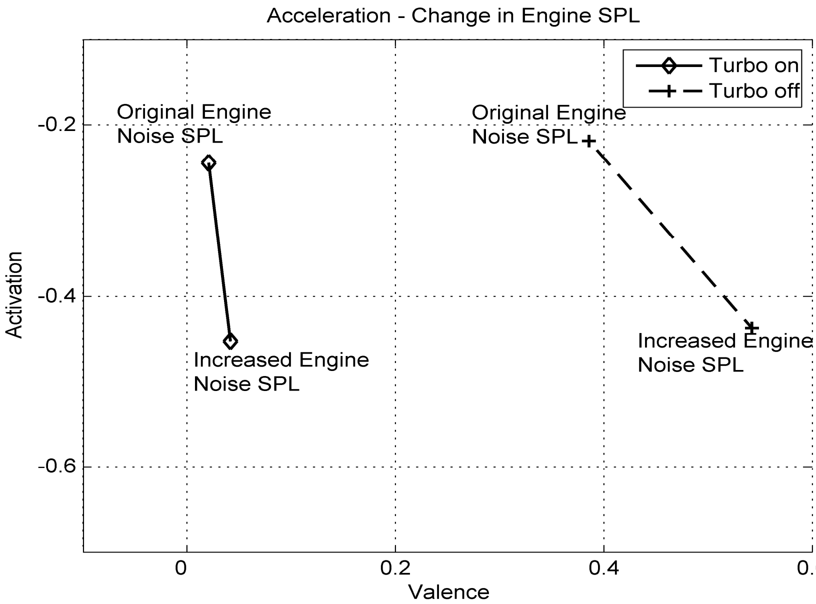


Figure 16 Effect of increasing engine SPL on the affection scales while turbo is on and off during acceleration

Moreover, in the figures decrease in activation caused by engine noise SPL seems to be independent from turbo noise, however, in Table 4, it is shown that the decrease when turbo noise is removed is not as significant (F=2.690, p=0.123). Nonetheless, there still seems to be a tendency.

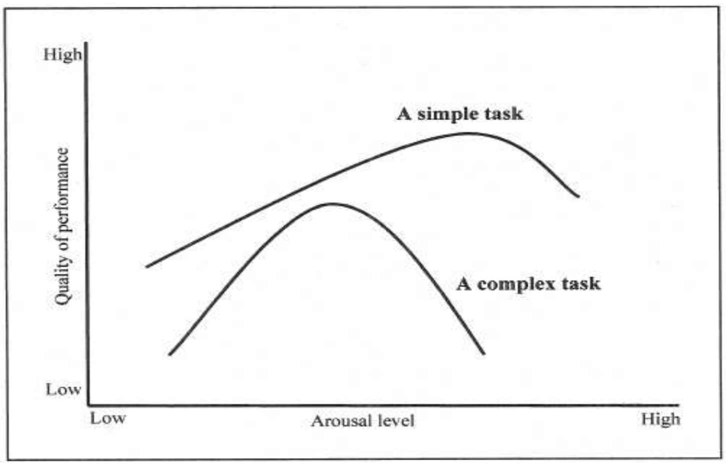


Figure 17 The Yerkes-Dodson model of arousal and performance

Increasing broadband noise SPL during constant speed driving, caused a significant decrease on valence (F=7.773, p<0.01). This effect, which can easily be seen in the Figure 18, can be explained by the property of broadband noise itself. In this study broadband noise was designed to be the noise left when one removes most of the information content from the sound, i.e. engine noise, turbo noise. Thus, when broadband noise SPL is increased the sound inside the cabin obtains more noise-like character. Also, since the sound during constant speed driving is almost constant over time and increasing noise would mask other elements of the total sound, such as engine noise. Consequently, it is apparent that if a sound becomes more noise-like, it would not be as pleasant.

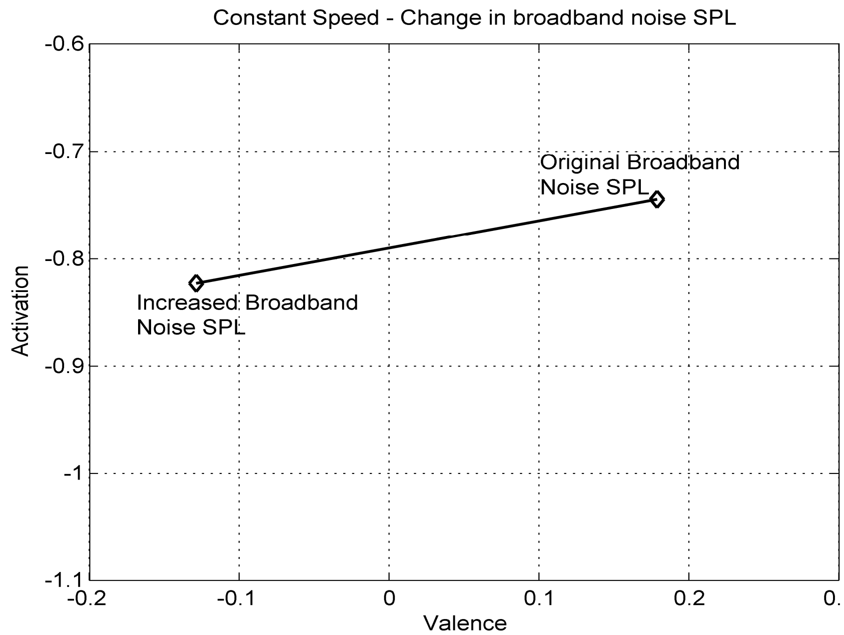


Figure 18 Effect of increasing broadband noise SPL on the affection scales during constant speed driving

Figure 19 shows the difference between two participant groups on the effect caused by increasing broadband noise SPL during constant speed driving. Truck drivers and students agreed on the effect on valence scale. However, it also caused activation to decrease for truck drivers (F=4.407, p=0.056). This can be explained by the larger experience that drivers have. Since increasing broadband noise SPL makes the sound more like noise, it becomes less activating for truck drivers. According to the Yerkes-Dodson model of arousal and performance (see Figure 17), one can say that this could be an undesirable effect. Since constant speed driving represents a simpler driving condition than acceleration, one needs to increase activation level in order to optimize performance.

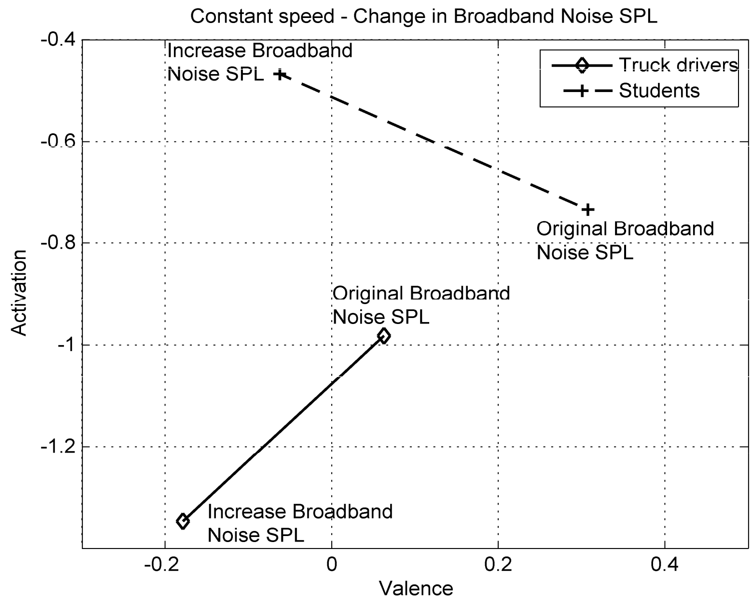


Figure 19 Effect of increasing broadband noise SPL on the affection scales according to students and truck drivers, during constant speed driving

7.2 Adjectives

When the effects of different parameters on different adjective scales were investigated, as a main effect it was found that there was a relationship between 'rumble' and engine SPL for acceleration case. One can say that this result is apparently due to the low frequent and rumbling characteristic of engine noise. Thus, increasing engine noise SPL caused an increase on 'rumble'. Another main effect was that removal of turbo noise caused a dramatic decrease on the adjective 'howling', in both driving conditions and for both participant groups. Since turbo emits a high frequent tonal noise this result is not a surprise.

Figure 20 shows the effect of increasing engine noise SPL on powerfulness and hearing how the engine was working during acceleration. In the plots, vertical axis shows two different SPLs of engine noise, i.e. 1 and 2 representing original level and 3dB increased level respectively. Solid line is the case when turbo was present and dashed line stands for the case when turbo noise was removed. It can be said that turbo noise had an effect on hearing how the engine was working. When turbo noise was present, increasing engine noise SPL had no effect. However, once turbo noise was removed, it became important to hear how the engine was working. As a result, it can be concluded that turbo noise is an indicator of how engine works during acceleration, and once it is omitted engine noise itself becomes important. Since turbo noise is higher in frequency than any noise inside the cab thus more distinguishable, this result seems reasonable. Moreover, one can relate this result to the significant difference found between the two participant groups in acceleration case. Removal of turbo noise in acceleration caused students to become much worse than truck drivers on hearing how the engine was working (F=4.712, p<0.05), whereas before removing the turbo noise difference was not significant. Therefore, one can conclude that turbo noise gives information about how the engine works, especially during acceleration.

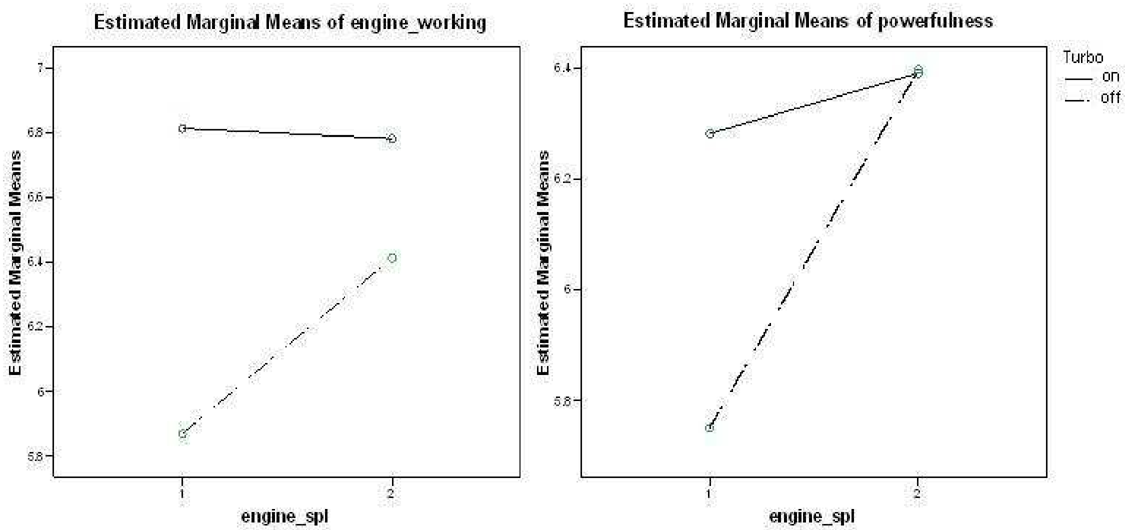


Figure 20 Effect of increasing engine noise SPL on 'powerfulness' (right) and 'hearing how engine works' (left) during acceleration (1=original level, 2=+3dB increase)

Moreover, increasing engine SPL seemed to increase powerfulness during acceleration, but when turbo was present the increase caused did not seem to be as significant as the one caused when turbo is off. Turbo noise had an effect on powerfulness as well. This could be due to same reason that turbo noise is more noticeable than other noises inside the cab, thus removal of it makes engine noise more important for the perception of 'powerfulness'. However, once engine noise SPL was increased, presence of turbo makes no change on 'powerfulness' (see right side of Figure 20). Therefore, it might be possible to reach the same powerfulness level without having the negative effects of turbo noise.

Figure 21 shows effects caused by increasing broadband noise SPL during acceleration, with and without turbo noise included. Similar to Figure 20, 1 and 2 on the vertical axis represent original level and 3dB increased level of broadband noise respectively. From the plot on the left, it can be seen that increasing noise made suitability increase (F=12.512, p<0.01) when turbo noise was present. Conversely, it tended to decrease suitability (F=3.340, p=0.089) once turbo noise was removed. This can be explained by the fact that increasing broadband noise might cause a masking effect for turbo noise which is high in frequency. Nonetheless, without turbo increasing noise would cause a decrease in suitability.

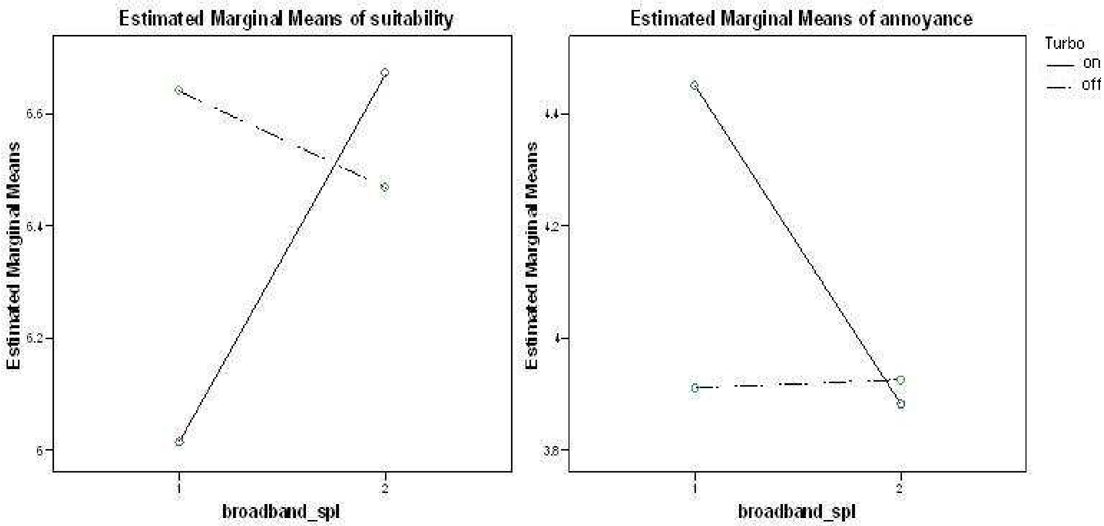


Figure 21 Effect of increasing broadband noise SPL on 'annoyance' (right) and 'suitability' (left) during acceleration (1=original level, 2=+3dB increase)

On the right side of the Figure 21, one can see the effect of broadband noise and turbo on annoyance during acceleration. It can easily be seen that increasing noise reduced annoyance (F=4.743, p<0.05) when turbo noise was present, but when it was removed increasing broadband noise level caused no change in annoyance. This effect, too, can be explained in a similar manner as for suitability. Increasing noise might draw attention away from the turbo noise, thus reducing annoyance. Therefore, it had no effect when there was no turbo noise. There was a similar result on the perception of 'quality' for acceleration case as well. Increasing broadband noise SPL caused an increase in 'quality' when turbo was present (F=25.022, p<0.001), whereas it tended to decrease 'quality' once turbo noise was removed (F=4.116, p=0.061).

Increasing broadband noise level and presence of turbo also had effects during constant speed driving. In the plot on the left side of Figure 22, it can be seen that increasing broadband noise level decreased suitability, but the decrease in the case that turbo noise was removed was more prominent (F=8.242, p<0.05) than in the case where turbo noise was present (F=0.912, p=0.356). This might be because presence of turbo noise caused suitability to decrease during constant speed driving (F=4.215, p<0.05), which can also be seen in the plot. Therefore, once turbo noise was removed, the effect of broadband noise on suitability became more significant.

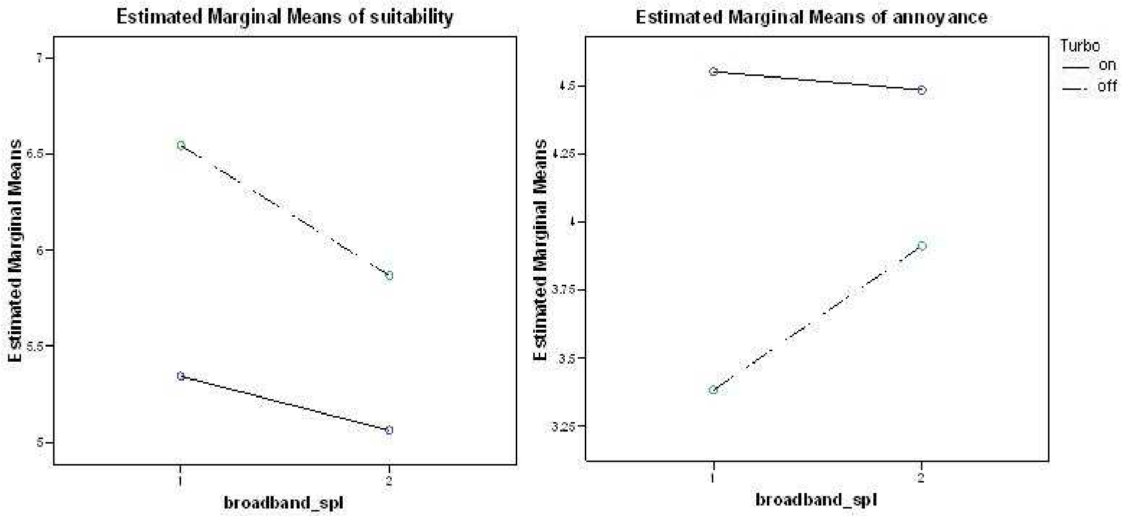


Figure 22 *Effect of increasing broadband noise SPL on 'annoyance' (right) and 'suitability' (left) during constant speed driving (1=original level, 2=+3dB increase)*

Similarly, in the plot on the right side of Figure 22, one can see the tendency that increasing noise level caused annoyance to increase when there was no turbo noise during constant speed driving (F=3.412, p=0.085). However, it caused no significant difference on annoyance when turbo noise was present. This might be due to the fact that turbo noise is more salient than other sounds, thus once it is omitted, one would be able to see the effect of broadband noise. Moreover, presence of turbo noise tended to increase annoyance in constant speed driving.

Figure 23 shows the effect of broadband noise level and turbo noise on howling scale during constant speed. When turbo noise was present increasing broadband noise SPL made it less howling (F=11.831, p<0.05). On the other hand, when turbo noise was not present increasing noise level made it more howling (F=8.194, p<0.05).

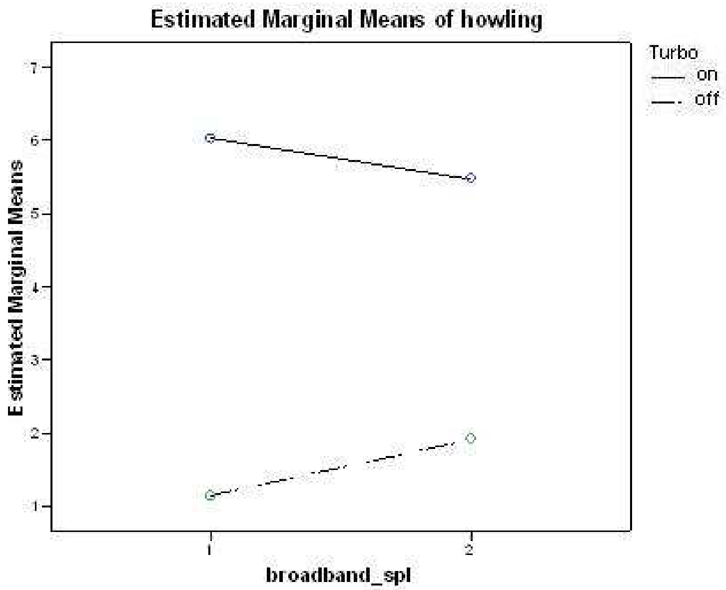


Figure 23 Effect of increasing broadband noise SPL on 'howling' during constant speed driving (1=original level, 2=+3dB increase)

This is an unexpected result since the adjective howling is used to rate tonal components in the tracks. Therefore, it is surprising that increasing noise level would cause a significant increase in howling. However, this might be explained by the confusion caused by the question itself. In the questionnaire, Swedish words '*tjutande*' and '*vinande*' were used. Those can be translated as '*howling*' and '*whining*', respectively. Although they were used to seek tonal components, participants might have rated those sounds with respect to their similarities with wind-like noise, but not sought tonal components. Therefore, this result may be just a confusion created by the question itself.

Finally, it was seen that although truck drivers were more consistent than students were in their answers, they did not disagree while rating general properties of the sound such as how howling, noisy and rumbling the sounds were. However, on some other adjectives that were used to seek the relation between the sound and real truck, i.e. powerfulness, quality, suitability and information content (how the engine was working); truck drivers and students disagreed to some extent. For instance, for acceleration case, for students increasing engine noise SPL tended to increase quality (F=3.250, p=0.095) and had no effect on annoyance. On the other hand, for truck drivers it tended to increase annoyance (F=3.843, p=0.069) but had no effect on quality (see Figure 12). Truck drivers' being more consistent is, of course, something that was expected from the beginning, since they are used to truck sounds and also know what kind of sound environment is better for them to work.

8 Conclusion

While investigating sources contributing to the sound environment inside the truck cabin, it seems that some of the sources like engine and turbo could be isolated adequately by the use of tracking filters. On the other hand, sources that emit broadband noise mostly due to aerodynamical effects are difficult to be isolated from the rest. However, one may be able to achieve that by using specific experimental setups.

In this thesis, unfortunately not all of the sources could be investigated due to practical issues. However, to some extent, one could see the effects of chosen parameters, which were under study, i.e. *'engine noise'*, *'turbo noise'* and *'broadband noise'*. In the light of the results, it can be concluded that increasing engine and broadband noise SPL affect user's preference and reaction in many ways for both of the driving conditions under study. Moreover, since turbo noise forms one of the most salient parts of the overall sound, its presence also affects user's preference and reaction.

In conclusion, one can say that by increasing engine noise level during acceleration, a better working environment for truck drivers might be achieved. It has been shown that during acceleration engine noise level have significant effects on activation level which influences task performance, impression of 'powerfulness' and information content, i.e. the ability of the driver to hear how the engine works. Also, increasing engine SPL caused activation to decrease for the acceleration case, which, as mentioned before, is a positive effect according to the arousal theory. Furthermore, it seems that turbo is an important part of the overall sound, since its presence seems to increase the ability of hearing how the engine works and the impression of 'powerfulness'. However, its presence has negative effect on the perception of 'suitability' of the sound to a truck, as well as it increases 'annoyance'. Those effects of turbo noise might be due to its high frequent and tonal, thus noticeable character. Therefore, with a smart design minimizing negative effects without harming its information content could make the sound environment inside the cab better. Another way could be removing turbo noise completely and alternate its information content by engine noise. In that way negative effects of turbo noise could be removed.

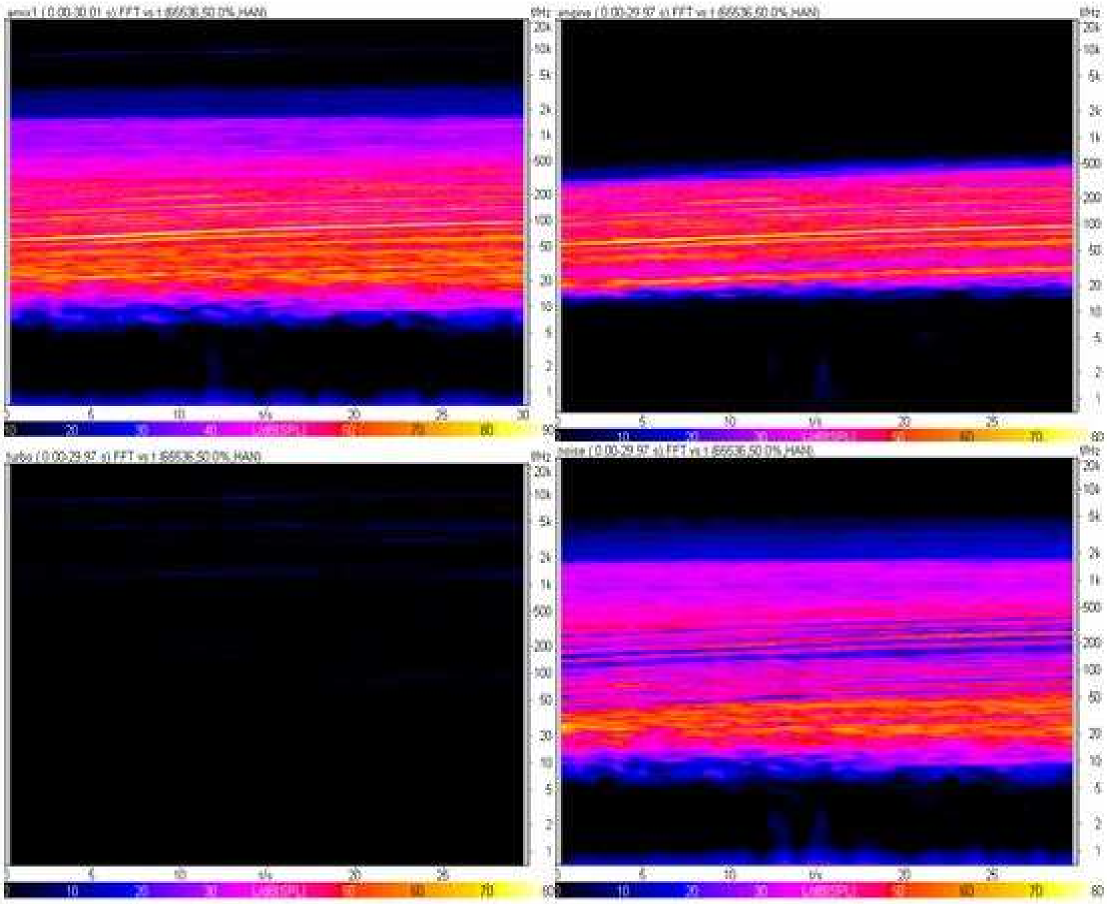
Similarly, it seems that it could be possible to achieve better sound environment in cabin during constant speed driving by decreasing the broadband noise level, since the results show that broadband noise SPL affected the perception of ‘quality’ and ‘powerfulness’, as well as ‘suitability’ of the sound negatively when turbo noise was not present. Practically, altering noise level might be done with effective use of absorbing material. Additionally, presence of turbo noise seems to have negative effects especially during constant speed, for instance on annoyance and suitability. Therefore it might be better to get rid of turbo noise during constant speed.

Moreover, with decreasing the spectral slope of broadband noise, low frequency content of the sound was attempted to be balanced. However, there were not any important effects caused by decreasing the spectral slope. It only tended to decrease tiredness.

Finally, one can say that effects of the selected sources were studied thoroughly in this thesis. For the future work, one might aim to isolate all possible sources by smart experimental setups, although this would be time consuming and in some cases unpractical to pursue.

Appendix A

Spectrograms of different noise sources under study for acceleration: overall noise (top left), engine noise (top right), turbo noise, (bottom right) and broadband noise (bottom left)



Spectra of different noise sources under study for constant speed driving: overall noise (top), engine noise (bottom)

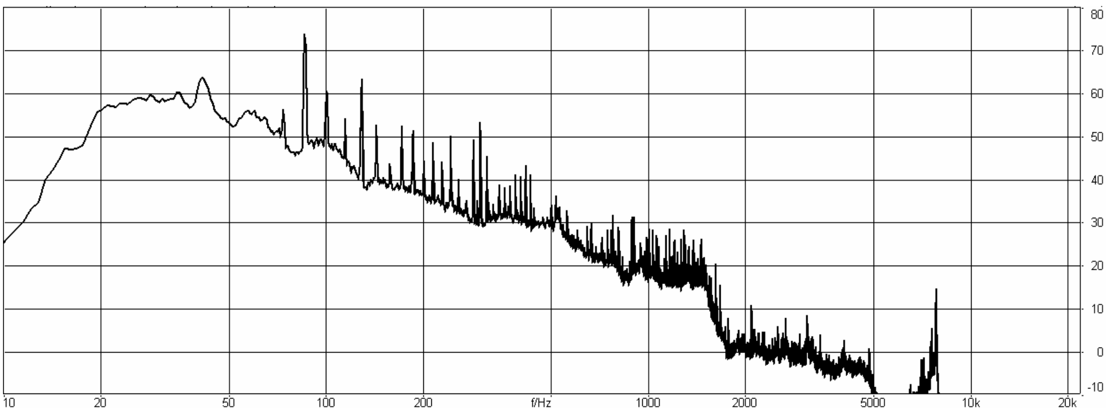


Figure 24 Frequency spectrum of overall noise for constant speed driving

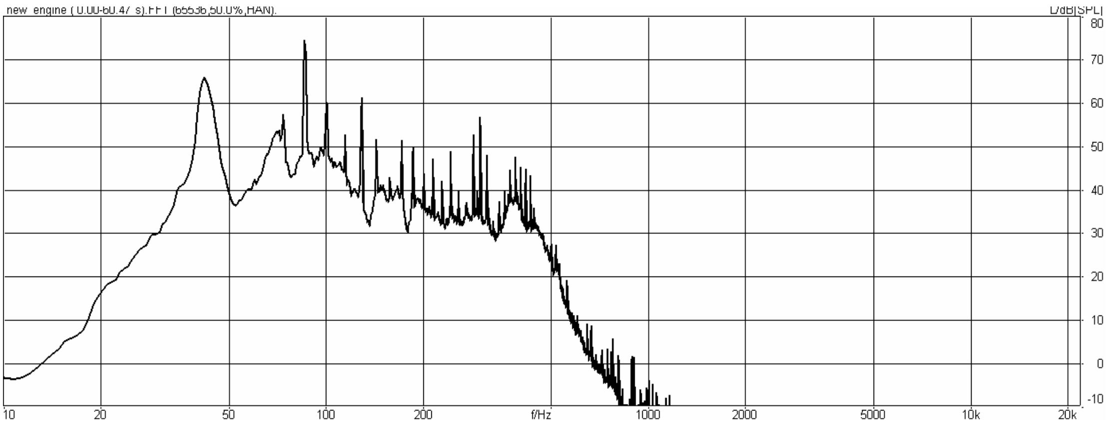


Figure 25 Frequency spectrum of the engine noise for constant speed driving

Spectra of different noise sources under study for constant speed driving: broadband noise (top), turbo noise (bottom)

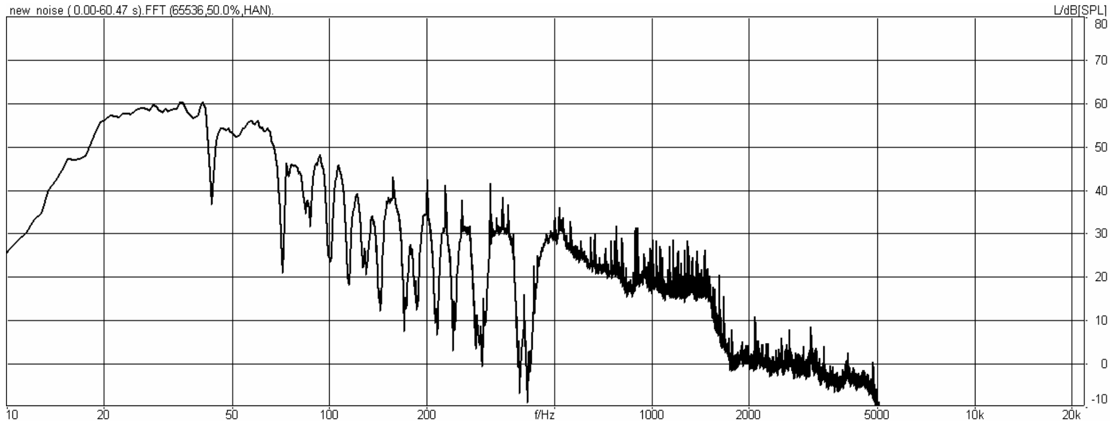


Figure 26 Frequency spectrum of broadband noise for constant speed driving

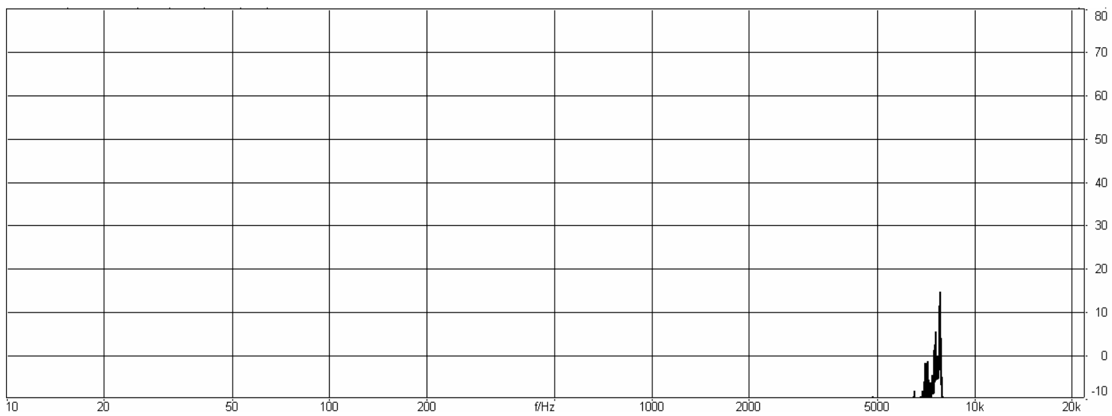


Figure 27 Frequency spectrum of turbo noise for constant speed driving

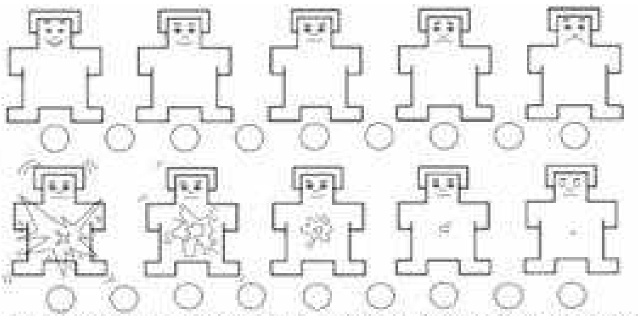
Appendix B

Questionnaire

LYSSNINGSFÖRSÖK
Bedömning av lastbilsljud

Välkommen till detta lyssningsförsök! Du kommer att få lyssna till ett antal olika exempel på hur det kan låta inne i en lastbilshytt. Efter varje ljudexempel vill vi att du svarar på ett antal frågor. Det finns inga rätt eller fel så svara bara vad du tycker och känner. Det är sammanlagt 32 ljud och försöket tar ca 45 min. Efter försöket får du en biocheck som tack för hjälpen.

Nedan ges några exempel på hur frågorna ser ut. Först kommer du att få bedöma hur **du** känner dig när du hör ljudet. Det gör du på två skalor som vardera består av fem stiliserade figurer. Genom att sätta ett kryss i en av de nio ringarna under den första skalan anger om du känner dig glad, positiv eller ledsen, negativ. På den andra skalan anger du på motsvarade sätt hur vaken, igång, alert eller lugn, trött, avslappnad du känner dig.



Du kommer först att få höra ett ljud som inte ingår i försöket och får då prova att markera ut hur du kände dig när du hörde ljudet för att få tillfälle att fråga försöksledaren om det är några oklarheter.

För varje ljud vill vi dessutom att du bedömer några olika egenskaper hos ljudet. Varje egenskap har en tillhörande skala och du svarar genom att ringa in den siffra som motsvarar ditt svar. **Du får inte sätta markeringen mellan siffrorna.** Ett exempel på hur en av dessa skalor ser ut visas nedan.

Tycker du att det låter som en kraftfull lastbil?

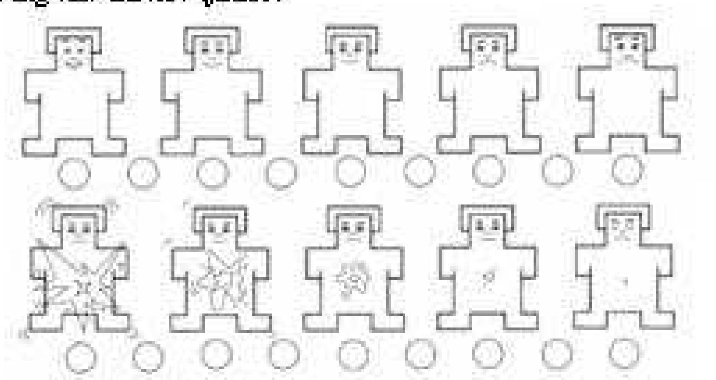
Inte alls										Väldigt mycket
	0	1	2	3	4	5	6	7	8	9

TANK INTE FOR LANGE PÅ VARJE FRÅGA! DET AR DITT FORSTA INTRYCK SOM ÄR DET VIKTIGA!
TACK FÖR HJÄLPEN!

ID:______ ÅLDER:______ KÖN:______

Ljud 1

Hur känner du dig när du hör ljudet?



Tycker du att ljudet är störande?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att det låter som en kraftfull lastbil?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att det låter som en lastbil av hög kvalitet?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att ljudet är tjutande eller vinande?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att ljudet är brusande?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att ljudet passar som lastbilsljud?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att ljudet är tröttande?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att ljudet låter dovt eller mullrande?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Tycker du att du kan höra hur motorn arbetar?

Inte alls — Väldigt mycket

0 1 2 3 4 5 6 7 8 9

Appendix C

Main effects caused by different parameters on affective scales and adjectives

Table 10 Main effects caused by changes in different parameters on the affection scales

	Engine SPL		**Broadband Noise SPL**		**Spectral Slope**		**Turbo**		**Driving Case**		**Drivers vs. Students**	
	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.
Valence	.000	.985	**5.356**	**.029**	.004	.952	.682	.416	.762	.390	.004	.951
Activation	2.379	.136	.049	.826	.001	.982	.022	.885	**3.337**	**.080**	2.013	.169

Table 11 Main effects caused by changes in different parameters on the adjectives

	Engine SPL		**Broadband Noise SPL**		**Spectral Slope**		**Turbo**		**Driving Case**		**Drivers vs. Students**	
	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.	F value	Sig.
Annoying	.689	.414	.000	.984	.139	.712	.912	.348	.122	.729	.069	.795
Powerful	2.517	.123	1.343	.256	.076	.784	.007	.933	1.946	.174	.340	.564
Quality	.065	.801	.252	.620	.048	.828	.074	.788	**2.963**	**.097**	.000	.996
Howling	.016	.900	.243	.626	.756	.392	**44.503**	**.000**	1.767	.194	.006	.938
Noisy	2.503	.125	1.342	.257	.068	.796	.003	.954	2.083	.160	.008	.931
Suitable	.021	.886	1.259	.271	.092	.764	**3.373**	**.077**	**5.428**	**.027**	2.361	.136
Tiring	.708	.407	.362	.552	**3.281**	**.081**	.585	.451	**9.251**	**.005**	.001	.973
Rumbling	**7.199**	**.012**	**3.961**	**.056**	**14.980**	**.001**	1.246	.273	1.936	.175	.214	.647
Engine	**4.619**	**.040**	**5.269**	**.029**	.636	.432	1.979	.170	**14.525**	**.001**	**3.631**	**.067**

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