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Speech Intelligibility Test in Virtual Reality for Interior Noise Evaluation

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ABSTRACT

An interior noise demonstrator is developed with the purpose of demonstrating and measuring the effects of noise reduction measures on passengers in the train. Improving the interior noise environment in the train is related to making the train a more attractive means for travel. A noise demonstrator, with visual stimuli presented in Virtual Reality, can support simulating mitigation measures, and executing experiments to proof the effectiveness of proposed measures. The demonstrator is capable of playing back synthesized noise predictions. A listening experiment in the form of a Speech Intelligibility Test (SIT) is described to evaluate the comfort of the train for different sound environments. Subjects were offered a virtual train ride in the demonstrator in which the SIT was built in as an instrument to measure the impact of the noise. In addition to the SIT also post run questionnaires were used, to measure the impact of noise on the subjects. Findings were that the SIT ratings indicated clearly that the different noises resulted in different SIT scores. The conclusion, based upon the given study, is that an interior noise demonstrator can simulate the noise experience of an actual train, and provides a platform for controlled research to measure, and eventually, improve passenger comfort.

Keywords: Noise, Interior, Virtual Reality

1. INTRODUCTION

Comfortable travelling becomes more and more important in the current global economy. With the worldwide focus on environmental impact, the train with electronic propulsion has a potential benefit, with respect to emissions, over other means of travel such as aircraft or automobile. The European Union has recognized this advantage and introduced the Shift2Rail programme [1] to not only cope with rising traffic demand on the road and prevent congestion, but also to address climate change. One of the main

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results of the programme should be quieter and more comfortable trains which attract more passengers.

In the DESTINATE project of Shift2Rail, noise impact is addressed and mitigation measures are proposed. A main objective is to introduce auralisation and visualisation solutions to demonstrate mitigation measures to stakeholders, such as manufacturers, policy makers, train operators, communities (that are concerned about rail noise), and passengers. For exterior noise, Swiss research institute EMPA has developed a demonstrator to auralise and visualise different train configuration and mitigation measures, such as wheel flats, iron cast or composite breaks, and noise barriers[2]. For interior noise, the Netherlands Aerospace Centre (NLR) has developed a demonstrator to do research and demonstrate noise impact for the purpose of passengers travelling aboard the cabin.

The case for improving the interior noise environment in the train is to make the train a more attractive means for travel [3]. With limited commuting time and distance, general speaking less than 30 minutes, this will not be a decisive discriminator to choose the train instead of other modalities. But for longer travel distances, such as long distance, high speed trains, an improved passenger comfort will make train travel more attractive compared to other means of travel, such as automobile or aircraft, See Table 1. To assess measures to reduce train noise, such as reduction of noise at the source, improved isolation of floor, roof, walls, or windows, or other means such as masquerading noise or active noise cancellation techniques, a noise demonstrator can help in simulating mitigation measures, and performing experiments to proof the effectiveness of proposed measures.

Table 1 Train categories and acoustic comfort

	Light rail, urban transport and metro	*Interregional and intercity service*	*Long distance and high speed service*
Duration	< 1 hour	< 2 hours	> 2 hours
Acoustic comfort	Less important	Important	Very important

2. DEVELOPMENT OF INTERIOR NOISE DEMONSTRATOR

An interior demonstrator was developed based upon experience with earlier projects with an exterior noise simulator [4][5] and an internal NLR experiment where cabin noise inside an aircraft was examined [8]. The use of Virtual Reality (VR) technology and binaural audio representation provides an immersive and realistic environment that has advantages over other solutions: First, a mock-up of an (interior of a) train is more expensive. Second, a mock-up is harder to move around and to demonstrate at different locations, while a virtual reality solution can run on a laptop computer. Third, a virtual reality solution provides means to add realism like outside view and the use of virtual questionnaires (see next chapter). Fourth, train interiors are developed using 3D modelling technology and thus these models can be reused in a virtual environment.

2.1 Audio representation

The interior noise demonstrator will provide an audio reproduction of prepared sounds. Sounds coming from the exterior will be auralised or recorded at the source and transfer functions will be applied beforehand to handle the characteristics of sound transfer through materials and effects of isolation. In the DESTINATE project, the Operational Transfer Path Analysis (OTPA) technique was validated for this purpose by DESTINATE partner Müller-BBM Rail [6]. Other interior sounds from within the cabin can be recorded or auralised as well and combined with the sounds from the exterior.

The demonstrator makes use of the Oculus Rift Virtual Reality headset and provides access to the head tracking of the test subject. Instead of the integrated headset, a noise cancellation headset was used to make it easier to demonstrate the platform at exhibitions. Using Head Relay Transfer Functions (HRTF) [7] implemented in the software libraries, a 3D binaural sound representation can be provided in the demonstrator. The Unity3D gaming engine is used and allows the placement of sound sources in the spatial environment of simulated cabin. For instance, Heat Ventilation Air Conditioning (HVAC) units can be placed overhead, while closing-door alerts can be placed near the train doors. No room acoustics were foreseen in the demonstrator, but diffused sound sources can be simulated by adding spatial blending to them.

2.2 Visualisation

The visualisation of the interior train demonstration is done with a combination of video replay and 3D objects. The interior of the train is presented by a 3D train object delivered by DESTINATE partner-project FINE1. Outside view recordings were made during a separate train ride done in the Netherlands between the cities of Lelystad and Zwolle with GoPro cameras, See Figure 1. By placing two video replay components just outside of the train object at both sides of the train, an optical illusion is created that the test subject is inside a riding train, See Figure 2.

Figure 1 Recording of the exterior view using GoPro cameras attached to the window.

Figure 2 The view from inside the demonstrator showing the outside view through the windows.

To provide the user with a better idea to be travelling in an operational train, additional computer-generated characters are added as passengers inside the train. These computer models look like computer-generated models. But while wearing the Oculus Rift Headset, their appearance is more realistic thanks to their real-life sizes. These characters were also linked with a motion model which allows them to move naturally. No additional audio sources were added for these characters, but can easily be added if needed for future research, such as examining the annoyance of people having phone calls or other conversations in the train.

3. METHODOLOGY

3.1 Research question

To access the impact of interior noise on passengers common research methods comprise questionnaires handed out to subjects after being exposed to the noise, either by headphone or in situ. The current experiment attempts to access the impact of interior noise in a more objective manner. The idea is that if background noise, or train noise, exceeds a certain threshold it will be more difficult to hear human speech within that noisy environment. Therefore, if it becomes harder to hear human speech, one can say that the level of comfort reduces. The Speech Intelligibility Test (SIT) is a tool that might be useful to measure this effect objectively.

This approach was applied earlier in the aviation domain [8]. However in the current study a VR environment (instead of just a headset in a very simple aircraft cabin mock up) was used to offer the subject the experience of a real train ride.

The above described approach was applied in an experiment in which the subjects were offered a virtual train ride in NLR's interior noise demonstrator and in which the SIT was applied as the tool to measure the impact of the noise on the subject.

The main research question was whether the combined interior noise demonstrator with SIT is a solid instrument to access impact of interior noise in trains on passengers.

3.2 Demonstrator set-up

The Demonstrator consists of a laptop, with Intel Core i7 processor, and a dedicated graphics card. This configuration is compatible with Oculus Rift CV1 VR headset. For headphones, a Bose QuietComfort 25 Noise cancellation headset is used. The rationale for using noise cancellation is that for demonstration purposes in noisy environments (such as community events or exhibitions), the headset helps in shielding surrounding noise from the user, but for the experiment described here this was not strictly necessary. Using the laptop screen, the experiment leader is able to see what the test subject sees, and also the progress is displayed within the experiment as an overlay message on the screen. The Oculus Remote, a simple wireless controller with some buttons, is used by the test subject to make selections.

3.3 Listening experiment set-up

To provide the means to conduct the SIT, a listening experiment is integrated in virtual reality of the demonstrator. The advantage of using this test is that the test subject (user of the demonstrator) does not have to take off the VR headset to fill in the test, and thus the person is not interrupted from its immersive experience of a train ride, See Figure 3. The test set-up consists of the following components in the simulation:

- A sound output emitting specific phrases for the test subject to recognize,
- a virtual piece of paper on the test subject's virtual lap with buttons to select the phrase that was heard,
- an "eye gaze" indicator exactly in front of the test subject's view that helped the test subject to look at the intended button, and
- an Oculus Remote controller in the hand of a test subject to make selections.

Figure 3 Point of View for test subject with Virtual Display in front showing SIT

The sounds that were spoken out, were uttered by four different male and female voices, and consist of syllables / phrases, such as "ABA", "AZA", or "USU". During the experiment, different cabin noise environments were presented for the train:

Sound 0: No noise, just silence as reference.

Sound 1: The noise of the train itself without any other noises, set to 66 dB(A).

Sound 2: Sound 1 plus noise of a HVAC system, set to 75 dB(A).

Sound 3: Sound 1 plus the noise of an alternative HVAC system, set to 71 dB(A).

Sound levels were calibrated by placing the headset on a Head and Torso simulator (See Figure 4) and measuring and adjust the sound level using a Rion NL-52 sound meter.

Figure 4 Head and Torso simulator for calibrating headset

3.4 Experiment

Initially the subjects were briefed about the experiment. The subjects were told why the project is executed and what tasks they were going to perform (like listening to noise, filling in questionnaires, and the SIT). This information was also disclosed in the "informed consent" form, which the subject was asked to read and sign.

Next, the subjects were given the pre-experiment questionnaire to fill in, which asked also about biographical data. Subjects were given the opportunity to familiarise themselves with the VR environment and the SIT. This was meant as a way to support subjects get used to the environment itself, the way the syllables were spoken and how to look at and select a syllable on the "virtual sheet of paper" in the VR environment.

After the familiarization stage, the experiment started. Noise samples were played continuously and combined with a syllable from the SIT. The subject's task was to point to the letters on the "virtual sheet of paper" describing how the syllables sounded.

Once the experiment was completed, the subjects filled in the final questionnaire about how they felt after being exposed to a VR environment during the experiment.

4. RESULTS

4.1 Subjects

Twenty-three people participated. There were no pre-requisites for the subjects except for them to have a good hearing.

The subjects were all interns (students) or employees at NLR. They were not paid for their contribution, except that there were plenty of snacks for them to eat before and after the experiment.

The sample group consisted of a total of 7 females and 16 males. The data of one subject (subject 21) was excluded after analysis from the data. This decision was based on the information that the subject performed poorly and had indicated to experience hearing problems, resulting in a final sample of 22 subjects. Their ages ranged from 22-54 years old, with a mean age of M= 33.65. They averaged 2.39 train rides per week.

4.2 SIT scores

The SIT ratings (see Figure 5) indicated clearly that differences in noise type and level resulted in different SIT scores. There were significant differences between the overall SIT scores ($P \leq .001$). Further there were no significant differences between male and female subjects.

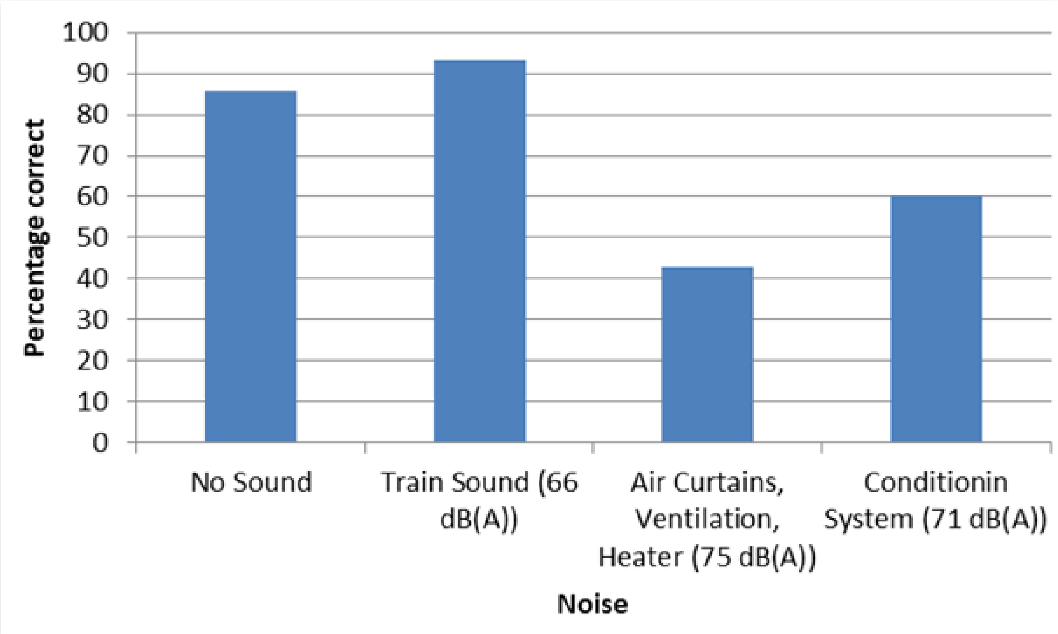

Figure 5 SIT scores for all noise conditions.

There were differences in how discriminative the different syllables were with respect to the four types of noise. In particular the difference between AZA and ASA was hard to hear.

There were no significant differences in how well the syllables uttered by these different voices were recognised.

5. CONCLUSIONS

1. The SIT ratings indicated that the error level increased in noisier environments

The test subjects recognize the syllables better in environments where the background noise level was lower. This also means that the means of using a “virtual sheet of paper” to indicate the syllables worked out as anticipated, and all test subjects were able to use the controller to indicate the right syllables.

2. The SIT in combination with the interior noise demonstrator is a relevant tool to measure the impact of noise on subjects.

The combination of a SIT test together with a noise demonstrator shows the usefulness for this set-up and can be applied in other domains where interior noise must be assessed as well. It can also help to give scientific support in situations where background noise is reduced and, thus, passenger comfort is supposed to be improved.

3. The simulation offers a controlled environment.

The use of a VR environment, which simulates a train with such a high fidelity, supports a controlled environment in which each subject can experience exactly the same situation. Therefore the system offers more control for researchers when they are designing and executing experiments about the impact of interior, or exterior, noise on subjects.

Potential next steps or further research are that a broader range of different syllables should be used to make the SIT a better, more sensitive, instrument. Furthermore, a validation of this SIT as tool for these kinds of purposes with other perception of noise assessment techniques including questionnaires, such as discussed at the International Commission on Biological Effects of Noise (ICBEN), should be performed to further validate the SIT at a scientific level of the work presented here.

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