CAN we improve acoustic environments by adding sound?

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Sound is central to the identity of a place, but is nonetheless a frequently neglected component in the design process. We believe that urban soundscape planning and product sound design has much to gain by collaborating with the artistic and humanistic fields of knowledge. Applying acoustics and perception psychology as well, the sound laboratory at Konstfack University College of Arts, Crafts and Design examined the domain of acoustic design in the research project ISHT – The Interior Sound Design of High-Speed Trains – in collaboration with, among others, train manufacturer Bombardier. Empirical data in this study is focused on train travel, but can easily be transposed to other contexts, such as public spaces. Methods for improving sonic experience in relation to criteria such as identity and specific needs were explored. Our thesis question was: How to create a comfortable and appealing environment by adding sounds (distributed via speakers)? The interdisciplinary research methods included field observations, listening tests, and quantitative data, as well as public exhibitions and collaborations with composers.

1 BACKGROUND AND AIMS

What is the difference between a location that appeals to us immediately and one that does not? How important is sound to that experience?

Konstfack (The University College of Arts, Crafts and Design) in Stockholm has recently completed a research project known as “The Interior Sound Design of High-speed Trains”, or ISHT, for short. The fundamental research question was: How can we develop design methods and acoustic

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artifacts to improve the sound environment of the high-speed train of the future? The project was carried out in collaboration with Bombardier, the train manufacturer; Sweden's Royal Institute of Technology (KTH); psycho-acousticians from Stockholm University; and ÅF (a Swedish technical consulting company. Today, good technology and what is good for mankind do not always overlap. This is why it was imperative to specify common interdisciplinary methodological tools for the design of sound environments, thereby linking sound design, artistic research, acoustics and psychoacoustics in this project.

This particular study focuses on the application of these issues on the interior of a train car. But in truth, they are essentially generic and can be applied to other areas, such as urban environments and public spaces.

When talking about designing our (urban) environment, the general sense would be the visual aspects, shapes and colors. Public spaces in a city are defined by the placement and height of buildings, the textures of surfaces, colors and light. Most individuals are highly unaware that sound also shapes both urban spaces and interiors. The importance of limiting and reducing noise levels is familiar, but how commonplace is it to regard sound as a design aspect? In spite of the fact that sound has a tremendous impact on creating strong environments, it has largely been ignored, though filmmakers have been aware its impact of since the dawn of motion pictures and they have refined the process of sound design to an art. The message of a particular visual scene can, with a conscious dramaturgy of sound, be utterly transformed by changing sounds and tell a different story. The image conveys different moods depending on subtle variations of sounds. A shift in a mood may be attained by way of a modified frequency spectrum, a change in the vehicles that pass off screen. Rhythmic elements like footsteps can convey time, class and the level of stress, while wind characteristics may say something about the season.

City noise is often merely regarded as a nuisance, or a hazard to be reduced as much as possible. Indeed, we know that noise, traffic, fans, etc. increases stress hormones and may result in health problems. Noise reduction is a constant work in progress that is adjusted to accommodate financial and logistical interests. But all these sounds also have a different function; they are part of the city's identity. Tall buildings that prevent the sun from penetrating into the narrow streets, that block the horizon, are a part of the definition of a city. Much in the same way, this goes for sound as well: A certain amount of background noise and accent sounds from traffic, construction, people on the move, etc, will make up a city's sonic identity. The problem today is the uncontrolled flood of sounds that threatens to overwhelm us. On our way through the city at rush hour, we parry, evaluate, sort, opt out and prioritize to avoid danger - and to not go crazy. Most of the sounds our minds are busy dealing with are not explicitly aimed at providing information useful to us, they are generally the result of a functional process: buses, cars, footsteps, swooshing doors and electric buzz. On top of that, add intentional sound to the mix: Advertising, keypad and phone tones, background music from stores, and so on. In order to deal with urban sonic development, we believe there is a need for a greater awareness of what shapes our acoustic environment. And this could best be achieved by an interdisciplinary approach, a critical discussion and complementary methods.

This approach has provided guidance in our project concerning trains. The sound in itself, not just acoustic calculations as to reducing dBA, is an important parameter in the overall design process aiming to optimize the travel experience on modern high-speed trains. Our study focused on the interior environment. Modern trains must meet a series of new requirements: Higher speeds, lower weight, and lower power consumption is vital in this day and age. The simplest way to improve acoustic conditions is to add mass, but this is in conflict with the need for mass reduction, which lowers energy consumption, material costs, etc. Therefore, it is important to pre-simulate how changes in a design would be able to improve these criteria, but also examine how the reduction of noise in a certain frequency band would improve the perceived sonic environment. It is not certain that a lower dB value is always preferable. Two possible improvements that both provide the same reduction in sound pressure can be experienced very differently. Our study, using simulated data from Bombardier, also explored what kind of technical improvements make the most substantial perceived improvement. However, these aspects will not be discussed in this paper.

2 A SHORT DESCRIPTION OF THE ACTIVITIES

The project was divided into the following phases:

1. Getting started: Data and auralisation
2. Evaluating potential improvements of the train
3. Non-attentional added sound environments
4. Attentional added sound environments
5. Interactivity, Infotainment

This paper will focus mainly on phases 3 and 4, though phases 1 and 2 will be briefly described. **(S**ee fig 1).

2.1 Auralisation – A Pedagogical Tool (phases 1 and 2)

A first step was to simulate the acoustics of a moving train, to evoke the soundscape inside a stationary train car by using an advanced sound system. Experiments were carried out at the sound lab at Konstfack and then implemented at the InnoTrans 2010 trade fair in Berlin. The system consisted of 10 channels of audio recorded during a test run with a modified Bombardier Regina train, also known under the name Gröna tåget (Literally: “Green Train”). They were fed to 16 Gennelec speakers, 4 woofers, 4 shakers mounted on the windows, and 2 buttkickers mounted on the floor. Visitors could interact with the sound through a touch screen. Different sound sources could be switched between "Standard" and "Bombardier optimized." In addition, the quality of the rail could be switched between two different positions. To investigate how noise from other passengers affected the sonic environment, a recording of someone having a cell-phone conversation could be activated. A central research issue in our study has been (phases 3 and 4): How can we improve the sonic environment by introducing sound elements, and what qualities are important when designing these sounds? To this end, three experimentally produced sounds could be activated from the screen when all other parameters were in "optimized" mode. The aim was to demonstrate the possibilities inherent in added sounds and stimulate a discussion on this subject. The added sounds will be discussed in more detail later.

Our simulation served as a platform for listening and communicating about these issues. Visitors were amazed at how effectively it illustrated the point, and as an pedagogical tool it was brilliant. The scope of this method to auralise environments is by no means limited to trains.

The evaluation of potential improvements was also carried out by way of two different *in vitro* methods: A) Group listening with pairwise comparison, where subjects compare pairs of four-second-long sounds, and B) Individual best/worst method, where subjects listened as long as they pleased to a set of sounds, and then selected what they felt were the best and the worst sounds. The results of these two tests showed a high degree of coherence.

The first experimental auralisation of the train in a sound lab served as a test environment for later stages of the project.

2.2 Masking Effect

On a train where many people are gathered in a small area, the train noise adds a certain quality in that it also creates a private zone by masking other passengers' voices. In our simulation at the fair InnoTrans, in Berlin 2010, visitors could clearly observe that with all the parameters switched to optimized mode - i.e. the lowest noise output – the masking of voices decreased.

2.3 Added Sounds

To improve the sonic environment of the train, we explored a more active form of sound design. Was it possible to design a sound that could be added to an existing space and thus create a long-term improvement of the sonic environment? The main concept here is informational[1] masking, as opposed to energetic masking. The idea is to divert the traveler's attention from the sound of the train.

The concept of different listening levels has been discussed by the French theoretician Pierre Schaeffer[2] who observed four modes of sound perception: Hearing, Listening, Attending and Comprehending (see also Amphoux[3] and Hellström[4]).

Each environment must be carefully analyzed with regard to a variety of aspects, such as social activities, target groups, intimacy, different needs, improving the travel experience, and so on. The basic assumption has been that the sound should be so faint that it just on the verge of being perceived or slightly less than that. It could be continuous, or in short or long intervals. Would it in fact be possible to create a sound environment that induced calm and provided a space for thought, even though the individual was not actively listening to the added sound? This thought was also posed by Brian Eno in his "Manifesto for Ambient Music".[5]

Active sound design like this was explored in two different ways: As non-attentional added sounds that could barely be perceived, and as attentional added sound that could clearly be perceived, but that was still very soft.

2.4 Non-Attentional Added Sound Environments (phase 3)

<u>Selecting /creating the sound textures to insert (phase 3.a)</u>

In this phase, we examined three sounds that were meant to be played at a barely audible level so that they were integrated/merged into the sound of the train. To obtain a relationship in terms of texture and eventfulness, we used the train's own sounds as a source and applied different filtering processes: **A)** A Shepard scale based on a sweeping bandpass filter, giving the impression of a falling tone that never reaches the bottom; **B)** Using extreme noise cancellation, so that only fragments remained; and **C)** Extracted tones harmonically related to the disturbing frequency.

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[1] Nilsson, M. E., Alvarsson, J., Rådsten-Ekman, M., & Bolin, K. (2010): Auditory masking of wanted and unwanted sounds in a city park. Noise Control Engineering Journal, 58(5), 524-531

[2] Schaeffer P. (1966): Traité des Objets Musicaux. Paris: Editions du Seuil 112-117.

[3] Amphoux, P. (1993): L'identité sonore des villes européennes. Cresson / EPFL IREC, Grenoble, 84p.

[4] Hellstrom, Björn (2003): Noise design: Architectural modeling and aesthetics of urban acoustic space. Bo Ejeby Forlag, Goteborg, 263 p.

[5] Brian Eno (1978): Manifesto for Ambient Music

(See fig. 2: sound c – harmonic structure)

The objective of the different added sounds was A**)** To play with the sensation of speed and travel experience**;** B) To create a more lively, or less monotonous, atmosphere; and **c),** To interfere with disturbing buzzing electrical components, transformers, or the like with a more or less fixed pitch. In this example, we analyzed the disturbing frequency and regarded it as a tone in a certain scale, such as C. By adding other tones (extracted by heavy filtering from the original train sound) that harmonically related to C, the disturbing tone becomes a function in a harmonic pattern. By randomly and slowly fading in and out harmonics D and E flat, above C, and B and A below, we wanted to explore if the disturbing sound was perceived in a different manner.

In vitro listening tests (phase 3.b)

Focus groups. The test was performed in the sound lab at Konstfack. Three groups of eight subjects listened, by way of loudspeakers, to three different discrete sounds against a background of a standard-level interior train atmosphere. The test subjects were not aware of the fact that new sounds had been added to the sounds of the train. After each of the three sound sequences, a group discussion was conducted in evaluation

2.5 Attentional Added Sound Environments (phase 4)

Selecting /creating the sound textures to insert (phase 4.a)

In phase 4, a more experimental empirical phase of the project, the sounds were meant to be audible, but still very low. We identified four important qualities to take into account and investigate further: *variation, indeterminacy, consonance* and *rhythm/pulse*. Our assumptions were multiple: Monotony can be countered by *variation*; unexpected elements loosen up the perception of sounds. *Indeterminacy* reduces the human brain's subconscious efforts to search for patterns in what we hear. Subtle *rhythmic elements* are thought to shift the focus away from low-frequency noise. A certain degree of *consonance*, i.e. tonal harmonic relationship, may have a positive effect.

Based on experiments, we decided to focus on *variation, repetition, improvisation* and *cycle* as basic concepts for creating four new sound sets. Two of the sounds were produced with musical instruments as sound sources while not trying to create music. To reduce the impact of our personal taste, we invited two composers to produce one 4-minute sound set each, based on a set of simple rules.

(A) - variation

Created by composer Lise-Lotte Norelius. Based on noise. Sounds evoking the train rail splice as a rhythmic element. In addition, a very soft, relatively high frequency, rhythmic sound, like a gentle scraping.

(B) - repetition

String Improvisation - violin and double bass. Natural harmonics plays an important part here. A calm, relatively steady flow around a tonal center that can be related to the natural train frequency versus velocity. A pulse slower than normal breathing is a prominent attribute.

(C) - improvisation

Improvisation - violin, double bass and saxophone. Here, unpredictability is a key principle. A wealth of small sound fragments mixed with the normal noise of the train. Occasional short high pitched falling sounds.

(D) - cycle

Created by Thommy Wahlstrom. Based on noise structures from the train's own natural sound, plus wind, water, etc. A very slow breathing movement, crescendo to diminuendo. A highly stylized swelling of ocean waves.

In situ listening tests - Casual personal trips (phase 4.b)

The respondents were asked to perform an evaluation on a train trip they would be taking for personal or business reasons, one that had no connection with this study in other respects. The respondents used their own equipment for listening: An mp3-player, cell phone or computer. They were asked to use open headphones and were able to borrow a Koss Port Pro from the lab if they wished. The files were delivered as 4 mp3s, each with a duration of 4:30 minutes. Each respondent listened to the sounds in a different predetermined order. A reference file with noise, filtered according to the profile of a standard train was also enclosed. The respondents were asked to calibrate their listening level by first listening to the reference file while the train was running in high speed and then set the level so that the reference sound was just barely audible, but not more. This procedure ensured that all files were played back at intended levels.

The four sound sets could be listened to and evaluated by way of a printed document. Each sound was evaluated with the following pairs of attributes: Stressing – Relaxing, Annoying – Pleasant, Dull – Exciting, Chaotic – Calm, Uneventful – Eventful.

(See fig. 3)

3 RESULTS/IMPLICATIONS

Our research project deals with the development and evaluation of a design methodology for acoustic design, primary applied to high-speed trains, but one that also has a scope that corresponds to urban spaces as well. The objective has been to redesign and improve the sonic atmosphere by adding sounds to an existing environment.

We investigated how subjects perceived merging sounds as well as ways of creating added sounds. The lessons learned from our experiments with sounds applied to the train environment led to a methodology that aims to critically examine the appropriate approach to different sonic environments, a means to single out important qualities and to create an understanding of complex sound environments and the potential of additive sounds.

3.1 Non-Attentional Added Sounds

The three sound sets A), B), and C) were perceived very differently. A**)** The experience of the falling Shepard tone was regarded as unpleasant, as it was perceived to be in conflict with the experience of the train movement itself. B) Extreme noise cancellation was regarded as much more positive, as it produced a sensation of opening up and thereby providing a more lively environment. C) The added harmonics made the perception of the disturbing tone less annoying. Shifting the focus from the disturbing tone and putting it in an organic context proved to be an efficient method.

3.2 Attentional added Sounds

The result from evaluating our second in situ experiments with pairs of attributes was reduced to two main qualities, pleasantness and eventfulness; a method developed by Axelsson et al. (2010), which is similar to methods by Russel and Pratt (1980) as well as Västfjäll et al. (2003). In terms of the quality “pleasantness”, a clear preference could be seen for concepts B) repetition and D) cycle. Both these examples have clear similarities regarding the time and form of phrases, but they differ a great deal with regard to frequency spectrum. The spectrum seems to be a less important aspect in terms of comfort. The concept of C) improvisation was regarded as a more negative experience. The concept A) did not yield any conclusive results. In terms of the quality “eventfulness”, no significant differences could be seen. (See fig. 4)

4 CONCLUSIONS/SPECIFIC VALUE AND MEANING

4.1 Research Methodology

Any esthetic choice must be made with an understanding of the factors at hand and with deep insight as to context and interaction. In an esthetic/artistic tradition, qualitative relationships are not easily formulated as statistics. In sound design, as in architecture, all parts must be seen in a context and related to. And, like architecture, sound is part of a subjective art form. Our objective was to gain more in-depth knowledge of the many features of as soundscape.

To assess the effect of how added sounds are experienced, we used both quantitative and qualitative methods.

Focus groups were used as a qualitative method; the subjects listened to sounds and discussed them. This provided us with a deeper understanding of the listening experience. By also using quantitative methods, we gained a great deal of insight into the way human beings perceive soundscapes.

4.2 Difficulties

We encountered a number of problems with the listening test methodology. In a lab environment we can never reproduce fully realistic sound. In particular, vibrations and movements are impossible to reproduce accurately. Obviously, the visual impression is far from an actual moving train, and it is not realistic to spend the same amount of time as an average train trip would take in a lab.

When we conducted our in-situ tests, the subjects wore headphones. We had no consistent control over the circumstances, the listening level, the character of the actual train sound, and so on.

One aspect both test methods had in common was that we wanted our subjects to assess sounds that were to be played at a barely perceptible level. Just by bringing their attention to the fact that these sounds were there obviously altered the conditions for what we intended to present, creating a paradox. In the future, we plan to conduct tests on trains in regular traffic situations with loudspeakers placed on shelves that emit very low-level sounds. The test will include a questionnaire for passengers (who then are not aware of the sounds) where they can provide feedback on how they perceive their sonic environment. The same questionnaire will also be given to passengers in an adjacent train car where no sounds have been added.

4.3 Conclusion

Carefully designed added sounds can improve/enhance environments previously experienced as noisy and uncomfortable. This is true for high-speed trains, and future experiments will show how this knowledge can be applied to urban spaces. This is a truly exciting field with a great deal of future potential that we intend to explore further.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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Fig 1: Activities in the project

Action		Method	Aim
1. Getting started: data and auralisation / Bombardier – Konstfack – ÅF			
1.a	Collecting data on train prototype	Multichannel recording and measurement	Rough material for an auralisation of the train environment (phase 1b)
1.b	Constructing a simulated sonic environment	Auralisation	To offer a virtual space for the development of several *in vitro* research methods
2. Evaluating potential improvements of the train / Bombardier – Konstfack – SU – ÅF			
2.a	Group listening test *in vitro*	Pairwise comparison	Evaluating the perceptual relevance of potential technical improvements of the train in terms of noise reduction (passive)
2.b	Individual listening tests *in vitro*	Best-worst method	As for 2.a, but realized individually in an immersive and open setting (listening time and order of the sequences)
2.c	*Innotrans* train fair, Berlin 2010.	Auralisation on a train model Itino	Scientific diffusion / public presentation of phase 2 in a static train.
2.d	3D sound-modeling	Auralisation methods	Development of simple auralisation tools and techniques to be used by manufacturers
3. Non-attentional added sound environments / Konstfack – SU – KTH			
3.a	Developing the sound textures to insert	Exploring sound characters / Pre-enquiries	Exploring and developing different sound textures – different characters- that could have a positive effect on the train environment. *In vitro* + *in situ* (explorative European high-speed train-trip)
3.b	*In vitro* listening tests	Focus groups	Evaluating, in group discussions, the resulting environment (train + “non-audible” added sounds)
4. Attentional added sound environments / Konstfack – SU – KTH			
4.a	Creating the sound textures to insert	Composition – Improvisation	Exploring different sound textures – different characters - with a potential positive effect on the train environment. Commission to external composers under specific guidelines.
4.b	*In situ* listening tests	Pleasant-Eventful qualification	Individual evaluation of the “attentional” soundscapes using personal devices and trip circumstances (the closest to “real” conditions)

4.c	*In situ* listening tests	Integration in “info-tainment” platform	Individual evaluation of the “attentional” soundscapes in organized trips and as a part of an interactive environment (phase 5)
5. Interactivity, Info-tainment / KTH – Konstfack			
5	Phone application / *in situ* tests	Sonification / Qualitative enquiry	Development and evaluation of interactive tool (phone application), integrating trip-information (sonification) and added sound textures

Fig 2: Sound c – harmonic structure

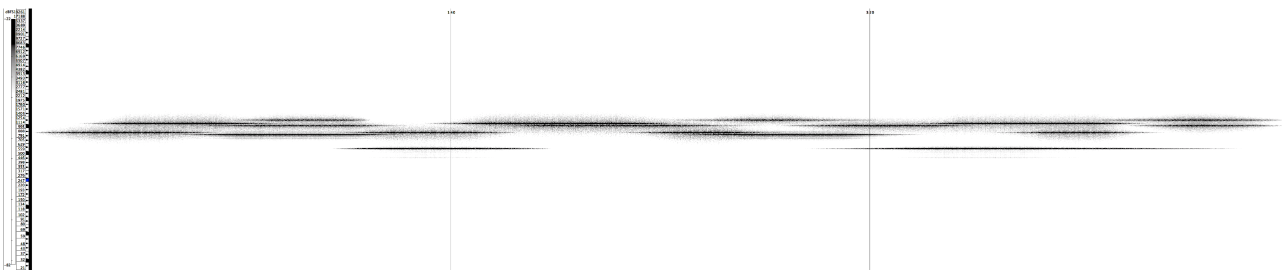
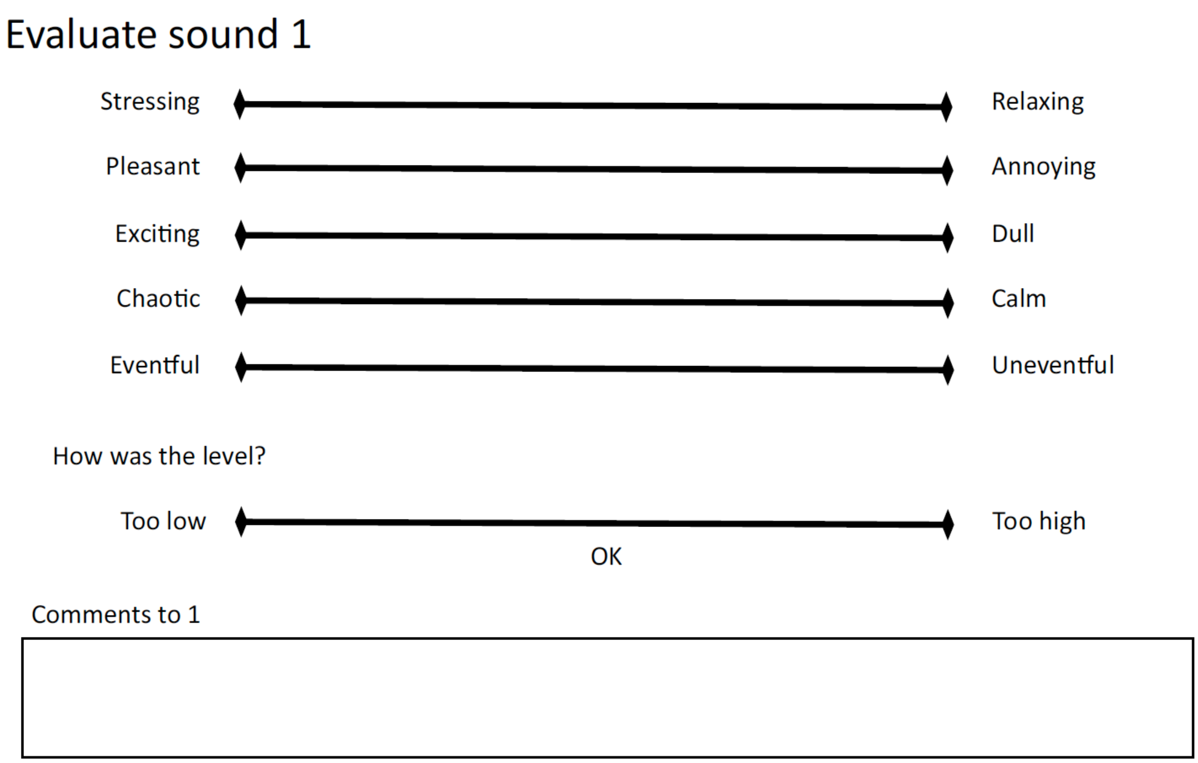


Fig 3: Evaluation document



Evaluate sound 1

Stressing — Relaxing

Pleasant — Annoying

Exciting — Dull

Chaotic — Calm

Eventful — Uneventful

How was the level?

Too low — OK — Too high

Comments to 1

(Fig 4: Pleasantness and eventfulness)