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Sounds for Enhancing Energy Efficient Driving: A Simulator Pre-Study

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ABSTRACT

Computer game technology was used for rapid prototyping of a sound based interface encouraging truck drivers to drive energy efficiently. The design process was inspired by user-centred agile methods. Interior sounds were made interactive by actively controlling them based on speed, engine speed, torque and acceleration. User feedback was collected at an early stage through contextual enquiry sessions during simulated driving. Based on the feedback the sounds were adjusted and effects on driver behaviour were measured in a simulator experiment. The effects on driver behaviour were small and not statistically significant (p>.05). However, assessments of preference and informativeness showed statistically significant differences between the design concepts (p<.05). The qualitative part of the study showed that the use of game technology for enabling assessment of interactive sounds in early design phases was useful and allowed for getting users into the loop early on. The framework was found to be suitable for designing interactive sounds, and the data collected provides insight into driver responses to using active noise control as a means for providing information to the driver.

Keywords: auditory display, active noise control, user-centred design

1. INTRODUCTION

New in-vehicle information systems and advanced driver assistance systems are currently being introduced in vehicles in order to help driving safely and energy efficiently. These systems help the driver to pay attention to critical events (e.g. collision warnings and blind spot information systems) or deliver important information (e.g. speed limits and navigation instructions). Safety and environmental impact are most of all dependent on the behaviour and attitude of the driver (1, 2). Even though it might be difficult to change drivers' attitudes, it is likely that drivers will be more motivated to change their behaviour if they are provided with the information necessary to understand the vehicle and adapt to the conditions. Within the SEEED (Sounds for Enhancing Energy Efficient Driving) project active noise control was studied as a means of providing information useful for understanding how the vehicle is driven with regards to energy efficiency. By using the natural combustion engine sounds as a base and by modifying them using active noise control techniques continuous feedback could be provided without preventing the driver from keeping the gaze on the road. Sounds were designed using user-centred agile methods and were assessed in a simulator experiment.

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1.1 Advanced Driver Assistance Systems

The literature on design of multisensory user interfaces in cars is extensive, typically involving graphics, sounds and haptics, and there are guidelines for how to design such interfaces (3). Much of this research is implemented and utilised by the automotive industry. Although the guidelines are scientifically well-founded they leave many decisions open to the designer. Extensive research in energy efficient driving also exists. For example, it is well known that energy consumption is highly dependent on driving behaviour, and hence also on the skills and attitudes of the driver. It has been shown that eco-driving can reduce fuel consumption by 10%, on average and over time (4). Research on driver assistance systems encouraging eco-driving has shown an 8% average decrease in fuel consumption for light commercial vehicle fleets (5). Research on gamified driver assistance systems has shown potential to change people's attitudes and behaviour and can be a powerful means to promote green driving (6). Steinberger et al. (7) made an extensive literature review on game design and discussed how games could make safe driving more fun, engaging and less boring without distracting the driver. However, most concepts are based purely on visual communication with the driver. User interfaces based mainly on sound may facilitate safer interaction, allowing an increase in the introduction of continuous feedback to the driver. In a previous study, Nykänen et al. (8) explored the use of music and computer game sounds for helping drivers to increase eco-driving skills and lower fuel consumption. The aim was to design interactive sounds that facilitated continuous feedback. The effects on driver behaviour were not significant. The results were unexpected, as qualitative data suggested that the drivers intuitively understood and often appreciated the cues given. A possible explanation could be that subjects focused on the graphical information during the relatively short lab experiment. Preference assessments showed that drivers preferred driving without the audio based driver assistance systems. To conclude, the study showed that it is possible to design feedback sounds that can provide information to the driver continuously, but that it is a delicate task to design the sounds in such a way that they are accepted by the driver. Therefore, the aim of this study was to design new concepts based on experiences from previous studies, collect more data on driver preferences and behaviour, and finally study the function in a simulator experiment.

1.2 Auditory Displays

Vehicle manufacturers possess extensive knowledge in the field of human-machine interaction, and focus on designing user interfaces with safety and usability in mind. Much research has been conducted on the use of sound signals in user interfaces in cars (3), and vehicle manufacturers are making more and more use of sounds, typically in combination with graphics. Audio-only interfaces have great potential for becoming safe and usable for systems integrated in the vehicle, as they ensure that the driver's gaze can be kept on the road. Previous studies of audio based user interfaces have made use of beeps (9) or speech (10, 11, 12), and occasionally on manipulation of media content (8, 13). We have not found other studies making use of active noise control to provide information about the state of the vehicle through manipulated engine/powertrain sounds.

1.3 What Can Be Learned from Game Sound Design?

When active noise control technology is introduced in vehicles, the sound design task moves from traditionally trying to control and reduce noise to designing sounds as part of the feedback during operation of the vehicle. This design task resembles the design of sounds for computer games. Therefore, it is interesting to review how sound design is handled in computer game development. Design processes for game sounds vary widely among companies and developers. Collins (14) gives an overview of how game sound design is typically organised:

Pre-production mainly consists of planning. An audio design document is created. In the pre-production stage, the audio team generally only has storyboards, concept art, crude game play and character sketches to start from. One way to get started is to create a temp track, putting pre-existing music and sounds temporarily in place of the final composition, defining basic parameters from which the composer can work (14). This early sketch allows for listening early in the design process, something that has been shown to be crucial for development of design ideas (15). Another important part of pre-production is spotting, i.e. identifying objects, actions, environments, etc., that need sounds (14). At this stage, sketchy sounds aid creativity and communication within the development team.

In the **production** stage a playable prototype of the game may exist. If spotting was not done in the pre-production stage, it can now be made from the playable prototype. If a playable prototype does not yet exist, composers may create a series of scratch tracks (14). Scratch tracks are sketches, allowing for sharing and developing design ideas. This typically involves alteration in real time in the game engine. Game audio tools allow prototyping the integrations of audio in game simulations before the game is finished, and are powerful tools for sketching game audio during the design process.

Post-production implies that the production phase of visual edits, design changes, technical pipelines and game play have been locked down and finalised (16). Sound is mixed to adjust the interplay of all audio components. Experiencing the game play in the right context is essential for the post-production mixer (16).

1.4 User-Centred Agile Methods

Design of user interfaces is a multidisciplinary task, requiring deep knowledge in psychophysics (or in this particular case, psychoacoustics) and psychology, as well as methods and procedures for design and product development. Knowledge from psychoacoustics and psychology aids the development process, and enables early decisions on potentially successful design routes, avoiding known pitfalls. Examples are the choice of modality, choice of frequency content of the sounds to avoid masking, spatial positioning of sound sources to help the driver to keep attention on the road, awareness of the risk of cognitively overloading the driver with a too complex task, etc. However, the design options are still vast, and knowledge is built along the path of the project. A good final design is crucially dependent on how this knowledge is built and taken care of. One approach to handle this throughout the product development process is user-centred agile methods (8, 17, 18). The core idea is to organise the work into short iterations (sprints), listening to the evolving product frequently and repeatedly throughout the design process, and get users into the loop early on. Agile software development methods like Scrum (19) and XP (20) do not, in their standard forms, deal with usability issues. However, the way of working with repeated short iterations is well suited for interaction design. There have been a number of recommendations on how user experience and usability should be taken into account in the agile development process. Brown, Lindgaard & Biddle (21) studied how a small team consisting of a game designer, a learning specialist and a software developer interacted. They found that artefacts like sketches, lists and spoken stories were central in development meetings. They also concluded that using different kinds of artefacts in combination were more powerful than using only one kind. Beyer (17), and Deuff & Cosquer (18) suggest methodological frameworks for integration of user-centred design strategies into agile product development. The methodology used in this paper is developed from Beyer’s framework.

2. METHOD

A user-centred agile method (17, 18) was applied, based on rapid and numerous iterations, and supported by the use of a large number of sound sketches (15). The process was inspired by Scrum (19), and major elements from the Scrum framework were used, for example: the division of work into time-boxed sprints (outlined in Figure 1); User Stories, Product Backlog and Sprint backlogs; prioritisation of backlog items; and the general aim for always delivering a working result from a sprint. In Design Sprint 2 qualitative studies were performed based on Contextual Inquiry Interviews (22) made during simulated driving. This approach was used to increase the chances of success in identifying a design that significantly affects driver behaviour. Finally, in Design Sprint 3, the design was evaluated in a simulator study where driver behaviour was measured.

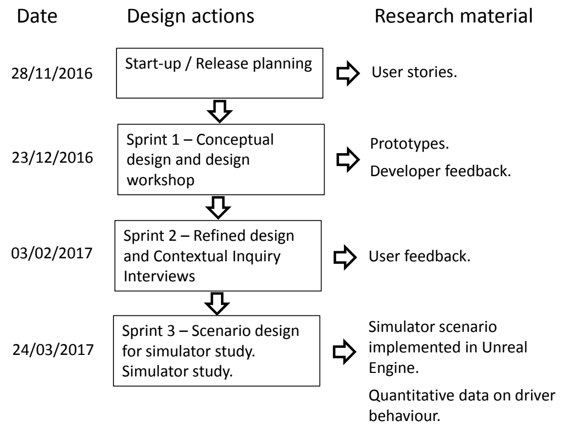

Figure 1 – A schematic view of the design and research process.

2.1 The Case and the Design Team

Scania Commercial Vehicles appointed the project team to design prototypes for an audio only user interface based on active noise control that would inform the driver about fuel consumption, energy efficient behaviour and deviations from an energy efficient speed. The prototypes were not addressed to a specific truck model but were intended to be concepts for possible use in future models. The design team consisted of three of the authors.

2.2 The Driving Simulation and the Sound Design Tools

To facilitate a rapid, iterative, and agile design approach, a prototyping environment was created based on a computer game engine. The game engine was used for creating a driving simulation controlled by a gaming steering wheel and pedals, and a game audio middleware was used for controlling sounds. This allowed the designers to test drive their designs in the studio, to invite participants to Contextual Inquiry Interviews, and to measure the performance of the final designs during simulated driving.

The driving simulation was implemented in Unreal Engine 4, based on the Advanced Vehicle template provided by Epic Games/Unreal Engine. A driving scenario consisting of a road resembling a rural road without other traffic was designed. The surroundings were designed as softly shaped mountains and hills in order to give a clear visual impression of moving around in a landscape, but were kept sketchy in order to communicate that the simulation was supposed to be considered as a sketch. To communicate the seriousness of the experiment and to give a realistic feeling of speed, the road and side barriers of the road were detailed with a high level of realism. A plain graphical representation of speed and gear was added. A screenshot from the simulation and a photo of the studio environment where the driving took place can be seen in Figure 2.

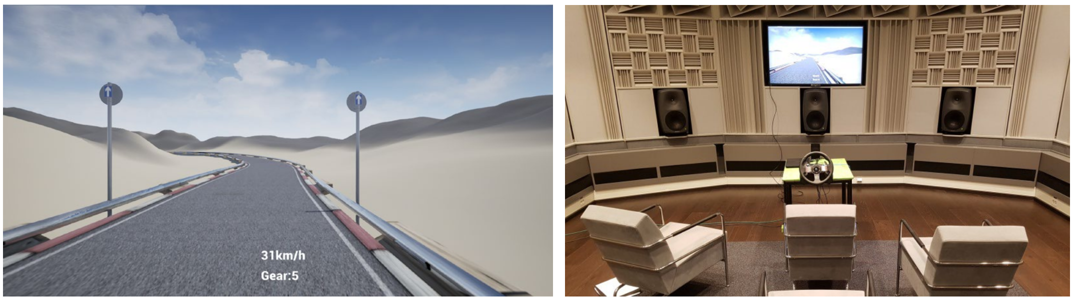

Figure 2 – A screenshot from the simulator and a photo of the studio where the driving took place.

The vehicle dynamics were adjusted to resemble truck driving, and an automatic gear box with 7 gears was used. Adjustment of the vehicle dynamics was made with professional truck drivers giving their opinions of the realism of the simulation. The truck sounds for the simulation were designed using conventional computer game technology. Engine sounds were recorded in the cabin during dynamometer measurements at different engine speeds and loads, tyre sounds and wind sounds were recorded in the cabin at different speeds during coast down with engine shut off. The sound files were pitch shifted and crossfaded based on speed and torque using functionality in the game audio middleware FMOD. By altering the mix and adding filters and tone components, engine sounds with different character were designed.

2.3 The Sound Design and Research Process

The design and research process outlined in Figure 1 was inspired by Scrum (19) and XP (20). A Scania representative acted as the product owner (Scrum terminology), and a number of user stories were defined at the start-up meeting. The project consisted of two sprints (Scrum terminology), and user studies were made through Contextual Inquiry Interviews (22) in the second sprint. All participating designers were asked to write diaries, and protocols were written from all designer meetings.

2.4 Start-up and Release Planning

In the start-up/release planning meeting a number of user stories were determined. In agile methods, user stories are typically one sentence descriptions of what a user wants to do with the product, written on the form: “As [kind of user] I would like [a feature] so that I can [reach a goal]”. The following user stories were defined in the start-up/release planning phase:

(i) As a driver I would like to hear how high the torque is.
(ii) As a driver I would like to hear the engine speed.
(iii) As a driver I would like to hear how fast I am driving.
(iv) As a driver I would like to hear if the speed is increasing or decreasing, or if I am driving at a stable speed.

2.5 Design Sprint 1 – Conceptual Design

The delivery from Design Sprint 1 was a prototype sound implemented in the driving simulator mimicking a real contemporary truck. The objective was to allow the designers to use this as a baseline for the design of interactive sounds that can, in the future, be implemented using technology for active noise control. In addition to this baseline sound, a number of sketchy concepts were designed. The sounds were used to support discussions with developers at a truck manufacturer. The sprint ended with designers and development engineers test driving the prototype sounds in the simulator, giving feedback and suggestions for further development. It was assumed that being able to interact with the sound interface in a fairly realistic setting is essential for making the right design decisions.

2.6 Design Spring 2 – Contextual Inquiry Interviews

The planned outputs from Design Sprint 2 were prototypes refined based on comments from designers and development engineers in Design Sprint 1. Nine concepts were developed and assessed in Contextual Inquiry interviews with four drivers in the driving simulator. The participants were test engineers at a truck manufacturer, who drive professionally for vehicle testing.

2.7 Design Sprint 3 – Experiment Based on Simulated Driving

The baseline concept and two other concepts were selected from Sprint 2 and adjusted according to comments from the Contextual Inquiry Interviews. A driving scenario suitable for a lab experiment was designed. It consisted of a road resembling a rural road without other traffic. No speed limits were indicated, but it was assumed that drivers would consider 80 km/h to be a suitable speed, as this is the maximum speed limit for trucks in Sweden. The participants were asked to drive as they would have done if they were driving a real truck.

Eighteen subjects participated, 4 female and 14 male, mean age 38 years (SD 10 years), all with a valid driving license for trucks. On average they had had the truck driving license for 12 years. The experiment started with a training session where all three conditions (Table 2) were driven for approximately 3.5 minutes each. The presentation order of the conditions was counterbalanced separately in all parts of the experiment (training, test, and preference assessments). After the training session the test session started. In the test session the three conditions were driven on the same track. Average speed, standard deviation of speed, throttle position and brake position were measured. Finally, the participants were given the opportunity to give their opinions on the different driver assistance systems. This was made by first driving each system for one lap, just to remind them about the conditions. Assessments were made on three 9-point scales: “How did you like this drivetrain sound?”, ranging from “Did not like at all” to “Liked much”, “I think this drivetrain sound provided me with enough information during driving”, ranging from “Do not agree at all” to “Agree completely”, and “I think this drivetrain sound was annoying”, ranging from “Do not agree at all” to “Agree completely”. In addition, an open box for free comments was provided.

3. RESULTS

3.1 Design Sprint 1 – Conceptual Design

In Design Sprint 1 a baseline sound was designed with the aim of creating a baseline that was perceived as realistic. This was made in a design workshop involving the three sound designers and three design engineers at Scania. In addition to the baseline sound, filtering techniques and engine order enhancement techniques (adding of tone components to the recorded engine sounds) were explored. The results from Design Sprint 1 was a working prototype with a balanced and realistic baseline sound and rough sketches of how the baseline sound could be altered using active noise control. No further qualitative or quantitative studies were made in this stage. Further development and assessment were carried out in subsequent design sprints.

3.2 Design Sprint 2 – Contextual Inquiry Interviews

Nine concepts were developed based on the feedback from truck designers and engineers in Design Sprint 1 (see Table 1). The concepts were then assessed in Contextual Inquiry interviews with four drivers testing them in the driving simulator.

Table 1 – Sound concepts developed in Design Sprint 2

No.	Description
1	**Baseline**. Designed to resemble sounds of contemporary trucks.
2	**Enhanced low frequencies**. Two distorted tones forming a triad chord with the fundamental of the engine sound.
3	**Enhanced low frequencies**. Same as 2, but another chord.
4	**Enhanced low frequencies**. Same as 2, but with more prominent feedback when the load was increased.
5	**Mid-frequency tones added**.
6	**Mid-frequency tones added**. Same as 5, but at a different pitch.
7	**Mid-frequency tones at constant pitch**.
8	**Mid-frequency tones added when speed is increasing or decreasing**. Higher pitch was used for increasing and lower for decreasing speed.
9	**Mid-frequency tones added when speed is increasing or decreasing**. Same as 8, but more prominent.

The interviews showed that:

- The baseline sound was experienced as realistic, but had too much wind noise, and the wind noise increased too abruptly with speed, especially around 60 km/h.
- The gear shifting sounds were unrealistic (no attempt was actually made to implement realistic gear shifting sounds).
- Opinions on rumbling low frequency sounds varied among participants. Some participants liked them, some did not.
- Most participants thought that sounds with more rumbling low frequency content sounded more realistic than the sound designed with realistic frequency content.
- Some participants though that low frequency rumbling increasing with torque gave good feedback. This kind of information is particularly useful on small hilly roads. However, most participants found it tiring, and would not like it for a whole working day.
- The turbo sounds were not realistically correlated with load. One participant said that he uses to listen to the turbo sounds to judge how much power that is used.
- One participant noted that there were differences between the concepts regarding when the response became apparent. When the auditory response came late (at high load) the tuck gave a weak impression. He preferred early response (already at low load).

The designers' reflections can be summarised into the following points:

- Immediate responses to driver actions were generally perceived as logical and desirable.
- Individualisation and possibility to switch the system on and off are probably necessary for broad acceptance, as preferences for sounds varied.
- Simulated driving in the design studio was useful for experiencing the interactive sounds.

3.3 Design Sprint 3 – Experiment Based on Simulated Driving

The baseline concept and two other concepts were selected from Sprint 2 for use in the experiment in Sprint 3, after adjustments according to comments from the Contextual Inquiry Interviews (see Table 2).

Table 2 – Sound conditions used in the simulator experiment.

No.	Description
1	**Baseline.** Simulated interior truck sound based on sampled, time stretched and pitched near field recorded engine, exhaust, and interior sounds.
2	**Increased low frequency rumbling used as feedback for torque.** Based on the baseline sound.
3	**Mid-frequency tones added when speed is increasing or decreasing.** Higher pitch is used for increasing speed and lower for decreasing. Based on the baseline sound.

Within-subject differences in average speed, standard deviation of speed and throttle position were analysed using one way repeated measures ANOVA. The results are shown in Table 3. No significant differences were found.

Table 3 – One way repeated measures ANOVA of within-subject differences.

	Within-Subject Effects		Mauchly's Test	
Variable	F	Sig.	$\chi^2(2)$	Sig.
Average Speed	F(2, 34) = 1.76	.187	1.907	p > .05
Std. Dev. of Speed	F(2, 34) = 0.545	.585	2.219	p > .05
Std. Dev. of Throttle Pos.	F(1.37, 23.36) = 0.300	.661	9.735	p < .05
Std. Dev. of Brake Pos.	F(2, 34) = 0.971	.389	4.065	p > .05

Within-subject differences in the subjective assessments were also analysed using one way repeated measures ANOVA. The results are shown in Table 4. Significant differences in preference were found (p<.05). Post-hoc Bonferroni adjusted pairwise t-tests showed that Condition 3 was significantly (p<.05) less preferred than Conditions 1 and 2. No significant difference was found between Condition 1 and 2. Further, significant differences were found in the assessments of how informative the sounds were perceived (p<.05). Post-hoc Bonferroni adjusted pairwise t-tests showed that Condition 3 was perceived as significantly (p<.05) less informative than Condition 1 and 2. No significant difference was found between Condition 1 and 2. Finally, significant differences in annoyance were found (p<.05). Post-hoc Bonferroni adjusted pairwise t-tests showed that Condition 3 was perceived as more annoying than Conditions 1 and 2. No significant difference was found between Condition 1 and 2.

Table 4 – One way repeated measures ANOVA of within-subject differences in the subjective assessments.

	Within-Subject Effects		Mauchly's Test	
Variable	F	Sig.	$\chi^2(2)$	Sig.
Preference	F(2, 34) = 20.176	.000	5.131	p > .05
Annoyance	F(2, 34)=10.7		0.47	p > .05
Information	F(2, 34)=8.76		0.10	p > .05

4. CONCLUSIONS

The design process used in the project was based on user-centred agile methods. It facilitated early and continuous feedback throughout the project. The use of game technology enabled designers and drivers to experience the sounds in a simulated environment. The framework was found to be useful and suitable for the design of interactive sounds, and the data collected provides insight into the response to the use of active noise control technology as a means for providing more information to the driver.

The effects on driver behaviour were not statistically significant at the p<.05 level. However, the preference assessments clearly showed that the prominent and informative tone components were not appreciated. However, individual differences were large. With a possibility to customise the sounds and with a better design that does not make use of continuous tone components for longer times, acceptance may be reached. The low rating of informativeness of Condition 3 indicates that the sound might not have been understood by the majority of the participants. With more time for training and clear instructions, other results may have been reached.

As the differences in driving behaviour were not statistically significant, conclusions should not be drawn. However, the test was short (3.5 min training + 3.5 min test per sound concept), and did not allow much time for learning. Further, the differences between simulated and real driving are large. We would therefore suggest that the design is further developed and tested in real driving. The user-centred agile sound design methodology was found useful, and we suggest that it is further developed.

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