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This is an electronic version of a paper presented at the *Interactive Audio Systems Symposium*, 23 September 2016, University of York.

It is available online in the proceedings at:

https://www.york.ac.uk/sadie-project//iass2016proceedings.html

Safe and Sound Drive: Design of Interactive Sounds Supporting Energy Efficient Behaviour

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September 23rd 2016

Abstract

The Safe and Sound Drive project concerns the design of an audio-only serious game for cars that will help drivers to increase eco-driving skills and encourage safe and environmentally friendly approaches to driving. The design process has been influenced by industrial design methodology and user-centred agile methods. Game engine technology and audio middleware were used for rapid prototyping. Sounds were made interactive by actively controlling them based on driving behaviour, and were designed to help and encourage a stable and suitable speed. User feedback was collected at an early stage through contextual enquiry sessions during real driving. Later, the system was showcased at two science festivals, where over 400 attendees test drove a game simulator. The agile design process provided continuous feedback to the project team, and guided the design of a version of the game that was evaluated in a simulator experiment. The results from the user studies suggest that opinions about beeps and audio signals vary among subjects whereas music and podcast based contents were generally better received. Alteration of media content by actively adjusting spectral balance or music mix formed working mechanisms for providing cues easily understood by participants. However, only minor effects on energy efficient behaviour were seen, suggesting that visual information dominated the determination of the participants' behaviour in the experiment.

1 Introduction

New in-vehicle information systems and advanced driver assistance systems are currently being introduced in cars 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). However, safety and environmental impact are most of all dependent on the behaviour and attitude of the driver [1], [2]. Mobile apps and games have been suggested as means to affect behaviour and attitudes, and there are already some mobile applications available for Android and Apple platforms, such as FuelLog, EcoDrive, Efficiency, and GoDriveGreen. However, none of these are designed for interaction during driving. The Safe and Sound Drive project concerns the design of a sound based serious game for cars that will help drivers to increase eco-driving skills and encourage safe and environmentally friendly approaches to driving. This is approached through the use of an audio-only user interface that enables continuous feedback, without preventing the driver from keeping the gaze on the road. Within the project interactive sounds controlled by driving parameters, such as acceleration and speed, were designed.

1.1 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 in the Safe and Sound Drive case are the choice of modality (hearing over vision), 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 all the way through. We suggest that user-centred agile methods [3], [4] are suitable for this. In particular, agile game development [5] is explored, as game design is a field where both graphics and sounds are essential parts of the product. 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. Game engine technology was used for rapid prototyping of concepts. Agile software development methods like Scrum [6] and XP [7] 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 [8] 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 [3], and Deuff & Cosquer [4] suggest methodological frameworks for integration of user-centred design strategies into agile product development. The methodology described in this paper is developed from Beyer's framework.

1.2 Psychoacoustics

Car 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 [9], and car 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 both for systems integrated in the car and for mobile applications intended for use while driving, as they ensure that the driver's gaze can be kept on the road.

The use of voice communication in user interfaces has also been thoroughly researched [10]. For example, Jeon, Walker & Gable [11] showed that speech messages can increase situation awareness and decrease perceived workload and anger levels, and thereby increase driving performance. However, the use of non-speech audio-only interfaces in cars has not yet been deeply explored.

It is well known that inattentional blindness increases with high perceptual load [12]. Studies have shown that vision and hearing, at least under some circumstances, share perceptual capacity. A high visual load can lead to inattentional deafness [13]. However, studies of the opposite, how a high auditory load affects inattentional blindness, are not coherent. Rees, Frith & Lavie [14] showed that perception of visual motion was unaffected by high auditory load. Schäfer & Fachner [15] showed that listening to music affected eye movements. However, they did not show whether the affected eye movements also altered the listener's attention. Beanland, Allen & Pammer [16] demonstrated that music can broaden visual attention, an effect that could be advantageous in driving situations. This effect was only observed for music containing voice. This was unexpected, as speech is known to be highly distracting. They also observed that adding an auditory task, consisting of detecting tones embedded in the music, resulted in a reduction of inattentional blindness, suggesting that higher levels of engagement with audio stimuli can result in higher visual awareness when task demands are low. However, for a demanding task, the addition of an auditory assignment may increase inattentional blindness. Designing sounds for user interfaces in cars therefore requires delicate considerations for balancing the cognitive load. In cases where the load needs to be raised, it may not be enough to just add music. Music with lyrics will attract more attention than music without lyrics. From these studies, it can be concluded that sounds used in a driving context can affect inattentional blindness and cognitive load of the driver. However, it is challenging to predict the effects.

Music tempo has been shown to have an impact on driving speed and performance in computer games, effects likely to be encountered in in real driving as well. Cassidy & MacDonald [17] showed that high-arousal music led to higher speed but lower driving accuracy in a driving game. They also asked the participants to estimate speed and accuracy. For high-arousal music, players underestimated both speed and inaccuracy. The combination of driving faster while underestimating the speed and inaccuracy is very risky behaviour. The study therefore supports the assumption that music can affect driving. Findings in the literature review as well as the feedback received during the agile user-centred process in the Safe and Sound Drive project [18], led to the implementation of music and speech based sounds containing continuous feedback on speed and momentary fuel consumption to the driver.

2 The Sound Design and Research Process

A user-centred agile method [3], [4] was applied to the Safe and Sound Drive project, including rapid and numerous iterations, and supported by the use of a large number of sound sketches [19]. The process was inspired by Scrum [6], 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. Repeatedly during process, qualitative studies and analyses were performed based on diary notes by the participating designers, Contextual Inquiry Interviews [20], and observation of participants. This approach increases the chances of success in identifying a design that significantly affects fuel consumption and driver behaviour. Finally, the design was evaluated in a simulator study where driver behaviour was measured.

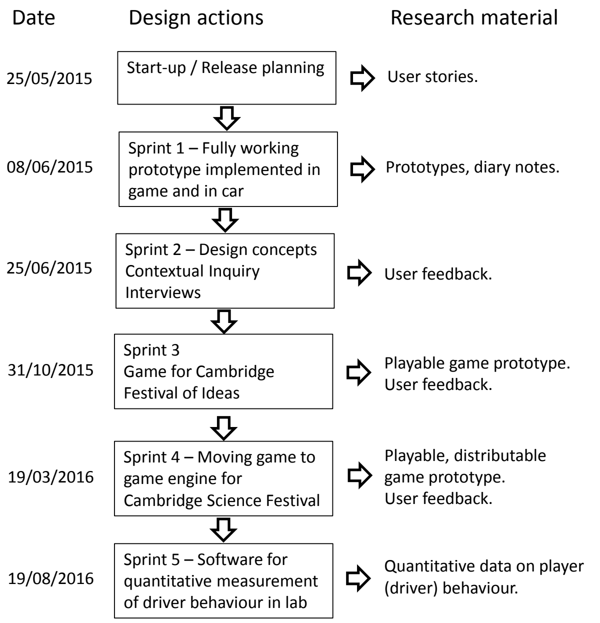

Figure 1: *A schematic view of the design and research process.*

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 when the fuel consumption is low.
(ii) As a driver I would like to hear when the fuel consumption is high.
(iii) As a driver I would like to hear when I am driving too fast or too slow.
(iv) As a driver I would like to hear when I am using too high or too low torque (too much or too little throttle).
(v) As a driver I would like to hear if I am driving at an even or fluctuating speed.

The available input from the car to the system was: speed, torque, speed limit, acceleration, and rate of change of torque. At the time of the project start, the car did not deliver momentary fuel consumption. Therefore, the two first user stories were not implemented. In Sprints 3 to 5 the design work was focussed on sounds to encourage an even speed as this is a key factor for fuel efficient driving and easily measurable in lab settings.

2.1 Design Sprint 1 – Prototype implemented in racing game and in car

The delivery from Design Sprint 1 was a fully working prototype, first implemented in a computer racing game and then in a real car. The objective was to allow the designers to develop and test-drive a number of sound concepts. It was assumed that experiencing the sounds in the right context is essential for making the right decisions.

2.2 Design Sprint 2 – Contextual Inquiry Interviews

The planned outputs from Sprint 2 were prototypes of sound concepts working flawlessly with all technical and perceptual issues raised in the review of Design Sprint 1 corrected. Nine concepts were developed (see Table 1) and assessed in Contextual Inquiry interviews with three drivers in a real car on a test track [18]. These interviews showed that:

- Opinions on beeps, and tones varied among the participants.
- Speech messages were generally not appreciated. The human nature of the voice messages may give rise to expectations on the system of performing and reacting like a human.
- Concepts based on music or podcast contents were generally well received. Alteration of music and podcasts, for example by adjusting BPM, music mix, volume or spectral content, could be used for providing drivers with continuous information, with a high level of acceptability.

Table 1: *Sound concepts developed in Sprint 1 and 2.*

No.	Description
1	**Speech only podcast**. Treble or bass were gradually decreased as the deviation from the target speed increased, treble when speed was too low and bass when speed was too high. A buzzing sound was played when speed started to deviate from the target speed.
2	**Pop music**. Treble and bass were adjusted as in Concept 1, and the same buzzing sound was used. Three rapidly repeated tones were played when the target speed was reached.
3	**Engine sound at too low speed and wind sound at too high speed**. Level increased with increasing speed deviation. A ding was played when the target speed was reached.
4	**Spoken messages**. Female voice saying "Speed is too low", "Speed is too high", or "good", in Swedish. Rapidly recurring tones were played with increased intensity as the deviation from target speed increased.
5	**Engine sound added both at too high and too low speed**. Level increased with increasing speed deviation. A ding was played when the target speed was reached.
6	**Engine sound controlled by torque**. Same as Concept 5, with the addition that the level of higher engine orders was gradually increased with increased torque. A ding was played when the target speed was reached.
7	**Recurring tones**. The repetition rate increased as the deviation from the target speed increased. Low pitch was used at too low and high pitch at too high speed. A slurping sound was added at hard acceleration. The level of the slurping sound was gradually increased as a function of torque. A ding indicated when the target speed was reached.
8	**Engine sound at too low speed and white noise at too high speed**. Noise filtered differently as a function of deviation from the target speed. A ding indicated when the target speed was reached.
9	**Loop based music**. Composed for the project. Three states were used: too high, too low and correct speed. The character of the music and the lyrics changed with state.

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 acceptance, as preferences for sounds and music varies. Altering a play list or radio program chosen by the driver and elaborating the content could be a way of dealing with the large differences in preferences.
- Addition of sounds, for example drums, when approaching the target speed created a feeling of flow. Therefore, concepts based on composition of sounds enhancing the feeling of flow at the target speed were developed.
- Simulated driving in the designers' studios was useful for experiencing the interactive sounds. However, the experience varied much between the studio and the real car. It was crucial to do final adjustments, e.g. adjusting levels, equalisation, responses to events, etc., in the car while driving.

2.3 Design Sprint 3 – Game Demonstrated at Cambridge Festival of Ideas 2015

In Sprint 3 gaming elements were introduced into the racing game/simulator. The game was intended for testing design concepts through demonstrations to larger audiences at science festivals. The game prototype included four sound concepts developed from the most successful designs identified in Sprint 2 (see Table 2).

Table 2: *Sound concepts developed in Sprint 3.*

No.	Description
1	**Speech only podcast**. Treble or bass were gradually decreased as the deviation from the target speed increased, treble when speed was too low and bass when speed was too high. A buzzing sound was played when speed started to deviate from the target speed, and three dings indicated that the target speed had been approached.
2	**Music, free choice from Spotify**. Treble and bass were adjusted as in Concept 1, and the same buzzing sound and dings were used.
3	**Loop based music**. The same as Concept 9 in Sprint 2 (see Table 1).
4	**Music mix.** Circus by Daisy and the Dark (from the Red Planet album app released for iOS at the App Store, 2015). Remixed depending on speed. Drums removed when deviating from target speed. At too high speed the mix was made intense and at too low speed calm.

The interactive sounds provided support to maintain a constant speed. Measures of simulated fuel consumption and integrated deviation from a given target speed were used to calculate an "eco-score". The game prototype was based on an open source racing simulator (CORS based on TORCS) shown in Figure 2. OBD-II messages were sent from the racing simulator to a Pure Data patch that interpreted them and controlled software synthesizers in Ableton Live through MIDI.

The prototype was launched at Cambridge Festival of Ideas 2015, where approximately 100 participants tried the game. Feedback to the project was based on one of the designers observing and interacting with the participants. It was felt that the opportunity to interact with such a large number of people gave a deeper understanding of user behaviour in general, and advantages and drawbacks with the design concepts in particular. This experience is supported by literature showing that having the development team taking part in user testing increases their understanding of the usability problems and makes them more sensitive to problems encountered by users [21], [22].

Figure 2: *Racing simulator, TORCS, used in Sprint 3.*

2.4 Design Sprint 4 – Game Demonstrated at Cambridge Science Festival 2016

The four concepts developed in Sprint 1-3 (see Table 2) were implemented in a driving game developed using the Unreal Engine 4 game engine. The FMOD game audio middleware was used to allow rapid prototyping of the interactive sounds. The main reason for this change of development platform was to allow for more flexibility in the design of scenarios and game ideas, as well as easy integration with game audio middleware. The new version was demonstrated at Cambridge Science Festival 2016, where more than 300 participants completed a test drive and eco-scores were calculated and presented. A very simple environment and car asset were used (see Figure 3), giving the impression of work in progress and making participants more aware of the objective of the demonstration, helping them pay less attention to details in the game play that were not under investigation.

Figure 3: *Computer game/driving simulator developed in Sprint 4.*

2.5 Design Sprint 5 – Experiment Based on Simulated Driving

Three concepts were developed based on concepts from Sprint 4. In addition, a baseline condition with only simulated interior car sound was included (see Table 3). A driving scenario suitable for a lab experiment was designed. It consisted of a road resembling a rural road without other traffic, with 30 mph and 60 mph speed limit sections alternating during the test drive (two sections with 30 mph and two with 60 mph limit). The sections were approximately of the same length. The participants were asked to try to drive as close to the speed limit as possible. The driving task was intentionally made quite difficult, with a car simulation that was sensitive to hills and to mistakes in the control of the vehicle. The car asset visible in the game used in Sprint 4 was hidden and a plain graphical presentation of speed and gear was added (see Figure 4).

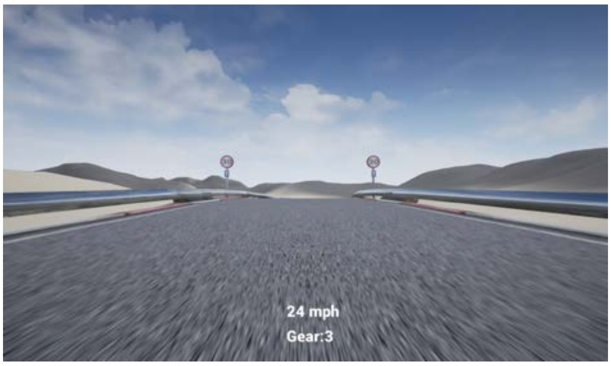

Figure 4: Screenshot from simulator used in experiment in Sprint 5.

Sixteen subjects participated, 7 female and 9 male, mean age 28 years (SD 14 years), all with a valid driving licence. The experiment started with a training session where all four conditions (Table 3) were driven for approximately 3.5 minutes each. The presentation order of the conditions was counterbalanced using a Balanced Latin Square.

Table 3: *Sound conditions used in the simulator experiment.*

No.	Description
0	**Baseline**. Simulated interior car sound based on sampled, time stretched and pitched near field recorded engine, exhaust, and tyre sounds, and wind sound recorded close to a rear mirror inside the car compartment. This interior sound simulation was played also in the other conditions.
1	**Music with treble/bass adjustments**. Monument by Röyksopp and Robyn (from the album Do It Again, Dog Triumph, 2014). Treble or bass were gradually decreased as the deviation from the target speed increased, treble when speed was too low and bass when speed was too high.
2	**Speech only podcast**. Treble or bass were gradually decreased as the deviation from the target speed increased, treble when speed was too low and bass when speed was too high.
3	**Music mix**. Circus by Daisy and the Dark (from the Red Planet album app released for iOS at the App Store, 2015). The music mix was changed as speed deviated from the target speed. Drums were gradually faded away as deviation from target speed increased. Base gradually faded away as speed increased above the speed limit. Synths and guitars gradually faded away as speed decreased below the speed limit.

After the training session the test session started. In the test session the four conditions were driven on the same track, but the track was driven two laps (i.e. approx. 7 min. per condition). The order of the conditions was counterbalanced using a Balanced Latin Square, but in another order than in the training session. After having finished driving one condition the participants were asked to rate how they felt while driving using the 9-point Self-Assessment Manikin (SAM) scales for measuring pleasure, arousal and dominance [23]. In addition, average speed and integrated deviation from the speed limit (target speed) 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 a short distance, just to remind them about the system. They could abort driving at any time when they felt ready to indicate their preferences and give comments on an assessment sheet. Assessments were made on two 9-point scales: “How did you like this driver assistance?” on a scale ranging from “Disliked very much” to “Liked very much”, and: “Would you use this driver assistance system if it was installed in your car?” on a scale ranging from “Not likely at all” to “Very likely”. In addition, an open box for free comments was provided. The order of presentation of the conditions was counterbalanced using a Balanced Latin Square in an order different from the training and the test.

3 Results and Discussion

Within-subject differences in average speed and integrated deviation from the speed limit were analysed using one way repeated measures ANOVA. Significant differences in average speed between the four conditions were found at 30 mph: $F(3, 45)=3.535$; $p<.05$ (Mauchly’s test of sphericity showed that the assumption of sphericity was not violated, $\chi^2(5)=9.71$; $p>.05$). Post-hoc tests were made using Bonferroni corrected pairwise t-tests. These showed that the only significant difference between pairs of conditions was between the baseline condition (no audio-based driver assistance) and Condition 1 (Music with treble and bass adjusted). Participants drove in average 1.1±1.0 mph slower when the music based driver assistance system (Condition 1) was used compared to the baseline condition ($p < .05$). No other speed related measures differed significantly between the conditions. The results suggest that this kind of continuous audio-based assistance has limited effect on people’s ability to keep an even and suitable speed during a short drive. A likely explanation is that visual information dominated the determination of the participants’ behaviour and performance in this experiment.

Significant differences in arousal between the four conditions were found: $F(3, 45)=3.562$; $p<.05$ (Mauchly’s test of sphericity showed that the assumption of sphericity was not violated, $\chi^2(5)=6.278$; $p>.05$). Post-hoc tests were made using Bonferroni corrected pairwise t-tests. These showed that the only significant difference between pairs of conditions was between the baseline conditions (no audio-based driver assistance) and Condition 1. Participants were in average 1.5±1.4 units less excited/more relaxed when the music based driver assistance system (Condition 1) was used compared to the baseline condition ($p < .05$). No other feelings were significantly different between the conditions. No significant differences between conditions were found for pleasure or dominance ($p>.05$).

Significant differences in the likelihood for a subject to use the systems in his/her own car were found: $F(3, 45)=5.912$; $p<.05$ (Mauchly’s test of sphericity showed that the assumption of sphericity was not violated, $\chi^2(5)=10.19$; $p>.05$). Post-hoc tests were made using Bonferroni corrected pairwise t-tests. Participants rated the likelihood that they would use the system based on music (Condition 1) 3.3±2.9 units lower than the baseline condition ($p<..05$), and the system based on podcasts (Condition 2) 3.3±2.4 units lower than the baseline condition. It is apparent from the results that the participants preferred driving without the audio based driver assistance systems, despite the small positive effect the systems had on driver behaviour. It also indicated that the alteration of music mix (Condition 3) was more likely to be used in real driving than the other two audio based assistance systems.

4 Conclusion

The design process used in the Safe and Sound Drive project was based on user-centred agile methods. It facilitated early and continuous feedback throughout the project. The use of game technology enabled designers to experience the sounds in a simulated environment in the studio and made it possible to interact with large numbers of end-user representatives in early phases of the project. 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 sounds used in advanced driver assistance systems.

The effects on driver behaviour were moderate. A significant effect on average speed could only be seen for one of the conditions, and only at the lower speed (30 mph). The speed fluctuation was lower for all conditions compared with the baseline condition, but none of these differences were significant ($p>.05$). The weak effect on driver performance was unexpected, as the qualitative studies in Sprints 1-4 had shown that drivers/players intuitively understood and often appreciated the cues given. A possible explanation could be that subjects were focused on the graphical speedometer during the relatively short lab experiment. Future research should therefore examine if continuous feedback through sounds can have an effect on long distance driving, for example by reducing mistakes when graphical information is missed.

The preference assessments indicated that the alteration of music mix was more likely to be used in real driving than the other two concepts. This is important for future development of continuous interactive sounds, as it shows that a well thought through design can affect the acceptance of the sounds. A major challenge for future audio based user interfaces is to design sounds with a high level of acceptability. The user-centred agile methods provide a toolbox for designing and improving future audio based user interfaces.

Acknowledgements

This project was made in co-operation between Anglia Ruskin University, Luleå University of Technology and Volvo Car Corporation. It was funded by the Swedish FFI – Vehicle and Traffic Safety programme, and by the European Commission through a Marie Sklodowska-Curie Individual Fellowship.

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