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How to deal with unsuspected source of annoyance in electric vehicle cabin using the “sonic augmented” concept?

Matthieu Duroyon¹
Renault Group - UTC - STMS Ircam-CNRS-SU
Full address

Patrick Susini²
STMS Ircam-CNRS-SU
1, place Igor-Stravinsky 75004 Paris

Nicolas Misdariis³
STMS Ircam-CNRS-SU
1, place Igor-Stravinsky 75004 Paris

Nicolas Dauchez⁴
UTC
Rue Roger Couttolenc, 60200 Compiègne

Louis-Ferdinand Pardo⁵
Renault Group
1 Av. du Golf, 78280 Guyancourt

ABSTRACT

The disappearance of the main source of noise with electric vehicles resulted in a breakthrough in car cabin sound experience. Despite significantly lowering the sound level pressure, one cannot claim perfect quietness is achieved. Indeed, as the auditory masking produced by the internal combustion engine is not effective anymore, unsuspected sounds such as electric whistling, whining or switching are now part of this sound environment and may be identified as unpleasant sounds. However, drivers expectations are to have audible feedback indicative of vehicle operation that matches their expectations. Therefore, the presence of unwanted and unpleasant sounds, on the one hand, and the absence of desired and informative sounds, on the other hand, is an opportunity for sound design to create a new sound environment inside car cabins. The present work proposes a “sonic augmented” concept based on the idea of adding designed sounds, called “masks”, participating both in the overall soundscape augmentation and in the attenuation of unpleasant sounds, called “defects”.

¹matthieu.duroyon@renault.com

²patrick.susini@ircam.fr

³nicolas.misdariis@ircam.fr

⁴nicolas.dauchez@utc.fr

⁵louis-ferdinand.pardo@renault.com

Sound design strategies with different parametrizations will be presented, as well as the results of two perceptive experiments which aim at evaluating the impact on perceptive attenuation of "defects" and the overall sound quality.

1. INTRODUCTION

Technical progress in the last decades, as well as evolution of automotive standards, lead to the reduction of sound sources. This evolution is even more blatant for the electric vehicle with the disappearance of the internal combustion engine. This is translated in the disappearance of wideband, noisy, but often accepted or expected masking sounds [1, 2]. Users listening habits have thus changed and turned the emergence of unexpected sound sources such as "Whining", "Electric Whistling" or "Switching noise" as named by acousticians [3] even more perceptible. The challenge of dealing with those electric sound sources is even more critical than the mechanical efficiency, such as electric engine or compressor efficiency are directly linked to their sonic signature. A more efficient engine is more likely to be more noisy [4].

The electric vehicle quietness has already been a subject for pedestrian safety [5]. A solution thus explored [6] was the design of exterior warning sound for pedestrian called AVAS, that is today mandatory for silent vehicle. This addition of an artificial sound, existent for more than 10 years on a car like the Renault Zoé [7]. This solution propagated the idea that sound design, as a field of study could tackle some of the challenges aroused by electric vehicle quietness. Thus, any additional designed sound, sometimes called active sound design, could be used to mask or treat emerging sound sources mentioned earlier.

Masking noises theory has been extensively studied [8, 9] and offers a complete framework on how to mask a signal using either tonal or wideband noise. The masked tone is thus below detection threshold and cannot be detected anymore at the unavoidable cost of increasing sound level perception. Such a solution, despite being effective to treat the question of detectability of an unexpected sound, do not offer a satisfying solution for the annoying aspect this sound has on the car cabin environment. On the other hand, the use of sonic media such as radio or personal music deals with the subject of comfort or annoying aspect of a car cabin, but do not deal with the detectability of the unexpected source.

The goal of this paper is to apply what we call sonic augmented concept. This concept consist in designing sound in a specific environment to improve pleasantness of a specific scene and decrease the annoyance related to an unexpected sound. In a first part a presentation of the sonic environment of the car cabin treated in this study is presented and the different sound designed for this sonic augmented concept. In the second part a presentation of the experimental procedure to be applied and a first pilot study.

2. CONTEXT

2.1. Sonic Environment

This study aims at quantifying the impact on user perception of a sonic augmented concept in the electric car cabin. This environment, depending on the vehicle, usage or context could host a wide variety of sounds. The verbal description obtained in [3] resulted in an online Speak lexicon [10, 11] that offer a list of word, a definition and audio example to describe and chose an environment to study. In this framework, a simple environment under control is needed. For this purpose, 3 categories of sound are identified: "background" sounds, "defects" and "masks". Background and defects are both inherent sounds of the electric car cabin. Background are sound being described as accepted or natural sound in the lexicon whereas defect are unaccepted, unpleasant or annoying sound. Masks are artificial sounds that will, in the augmented acoustic paradigm, be added to the scene formed by a background sound and a defect sound.

In this context, two sounds of the lexicon, one described in the lexicon as problematic

(defect) one as accepted (background) that could easily be recorded or reproduced are chosen. The background sound, defined as accepted in the car cabin, that is stationary, broadband and easy to record : Ventilation. In the following this accepted sound alone will be called "background". The defect is an annoying sound, stationary and emerging : aeroacoustic whistling. The exact sound used were recorded in the Renault Zoé from the driver position and mixed together through Max MSP [12]. Thus, the complete scene is composed of 2 different sounds, a defect and a background.

For this pre-experience we recorded several conditions with a ZoomH4nPro and a sound level meter B& K Type 2250-L in a Renault Zoé. Before any work, we first recorder a 1 kHz constant tone played by a mobile speaker with both the recorder and sound meter as a calibration signal. This protocol aims at keeping track of an estimation of the actual level of the sources we will work with here.

2.2. Augmented Sound Strategies

The background and defect are now selected and we explore strategies for augmented sounds to attenuate the negative perception induced by the defect.

The first strategy : energetic masking. It is the more intuitive one. It consists in adding energy in the same Bark's band as the defect to achieve a masking effect depicted by Zwicker [8]. The specific loudness in the defect Bark's band of the mask should be superior to the specific loudness of the whistling to achieve a complete masking, but constraints are free in other Bark band for a more expressive sound design. This strategy is called here "energetic masking". From a design perspective, the mask created is mocking the background sound properties to sound as similar as possible to the ventilation. The aim is that the participant does not identify this sound as a new sound object.

Second strategy : sound dressing. In opposition to the first strategy, it consists in acting on the defect sound. The aim is to add higher order or sub order harmonic to act on reduced properties of the sound and make it sounds more "bright", more "warm", more "harmonic" [13] ... From a sound design perspective, the added sound is aimed at changing the identification of the sound causes.

The third strategy : attention masking. It consist in willingly adding a supplementary object to the sonic scene. From a sound design perspective, this sound is more likely to hold intention and emotion because it is aimed at existing by its own. The designed mask is supposed to capture attention, acoustic properties such as higher values of brightness or roughness have been proven to be efficient [14] and inspired the composition of those masks.

2.3. Sound generation

Two masks were composed by the first author for each strategies through the Max environment. Those sounds were composed specifically for the background and defects identified earlier. Morevoer they were composed to be heard through headphones. Thus no effect of spatialization on masking or on sound identification were considered.

For each of the mask composed, different level of loudness and sharpness were used. Those 2 auditory features are known to be of first order impact on pleasantness and on detectability. An increase in loudness (or sharpness) is more likely to be unpleasant but also more likely to dissimulate a defect identified as unpleasant. Therefore we compose 3 level of sharpness, called Dull, Flat, Sharp and 3 level of loudness called Quiet, Neutral, Loud for a total of 9 level within the same mask.

Figure 1 shows the computed values for the 2 auditory features of loudness and sharpness for each masks and their level. The computation have been realized with Python Library MoSQITo [15]. The volume of each mask is adjusted in the global mix of the scene such as the total loudness of the scene is constant for each mask at a given loudness level. Therefore, as illustrated

Table 1: Overview of the masks distribution in strategies presented. Each masks possess 3 level on their loudness and sharpness auditory features for a total of 45 masks.

Mask Name	Strategie	Sharpness level	Loudness level
m3	First strategy	Dull, Flat, Sharp	Quiet, Neutral, Loud
m2,m5	Second strategy	Dull, Flat, Sharp	Quiet, Neutral, Loud
m1,m4	Third strategy	Dull, Flat, Sharp	Quiet, Neutral, Loud

in Table 1 the loudness of the masks alone are different. Figure 1 illustrates the changes on the second auditory feature, sharpness. The slightly changes in the sharpness value within the same sharpness level is due to the numerical model of sharpness that depends on the loudness.

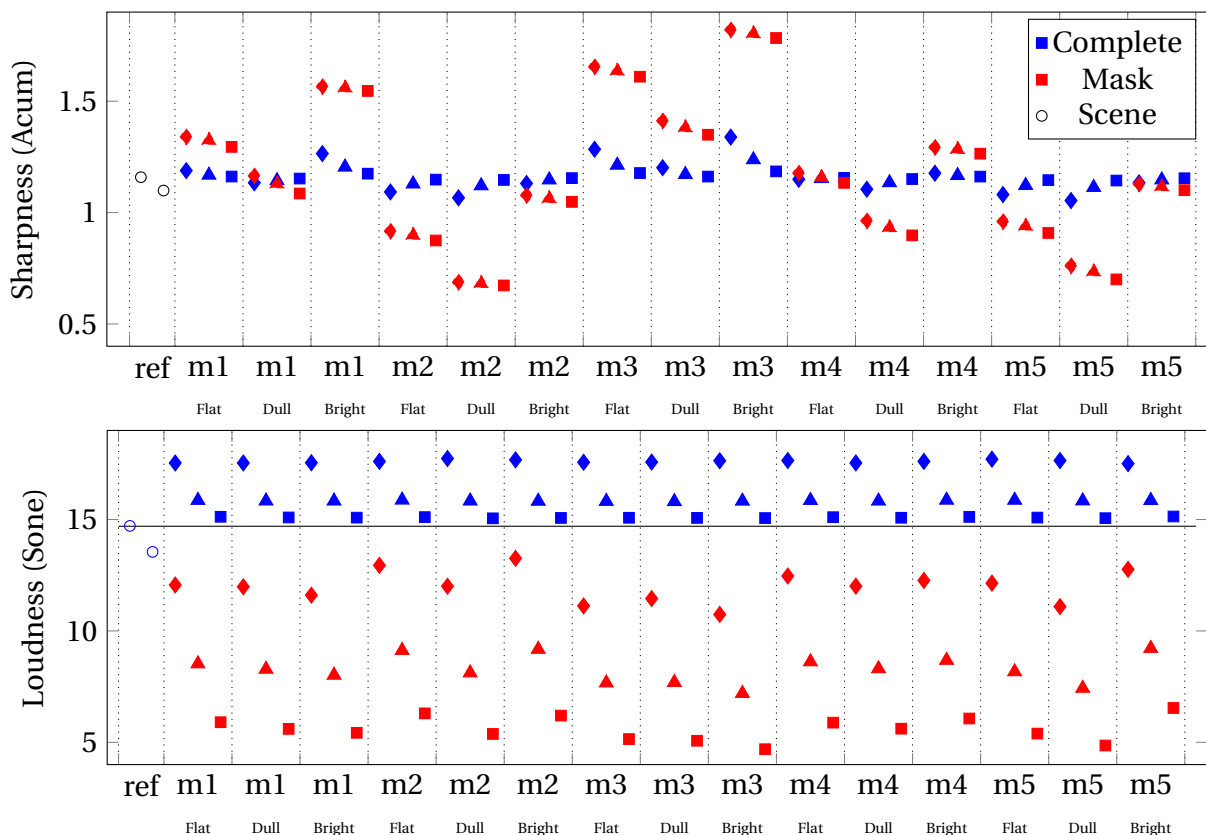


Figure 1: Computed sharpness and loudness with the ISO 532-1 Standard available in the MoSQITo Library for each of the sound stimuli in our experience. The loudness is computed both for the mask alone or the complete scene. The Loud condition is represented with a diamond, the neutral condition with a triangle and Quiet with a square.

3. EXPERIMENTAL EVALUATION

3.1. Perceptual Task

Electric car is a complex object possessing a variety of use cases. Therefore the question of comfort, that strongly rely on context elements [16, 17] is questionable to be applied on such a specific case of a non moving car. Therefore we will rather evaluate pleasantness modification by masks with the hypothesis that improving pleasantness on a controlled sound atmosphere could result in

comfort improvement in more complex use case. This pleasantness task will be evaluated without informing the participant of the defect and mask presence.

The second dimension we want to evaluate is the ability of the participant to hear the defect in the complete scene, what is called detectability in the following. This give a measurement of the ability of the mask to succesfully distract the user from the defect sound. To properly evaluate this dimension, the participant will be taught to recognize the sound by being presented the defect and background sounds separately.

Those 2 tasks are performed in two similar but independent tests. This is necessary because the training task in the detectability test, that helps the participant to recognize the defect could change the participant behavior in the pleasantness task once he knows there is a defect.

3.2. Best-Worst Scaling Procedure

The factorial conception of this experience, including 5 different masks, each one of them having 3 different levels of loudness and sharpness results in the composition of 45 masks. Each of those stimuli are presented in a defect and no defect condition for a total of 90 stimuli to evaluate. We add to this the two reference stimuli, having no mask added, a stimuli with and one without the defect. The number of sound to evaluate is important, moreover evaluated dimension may not be trivial for participants to evaluate. Thus a Best-Worst Scaling paradigm (BWS) has been chosen. This paradigm has proven to give consistent results [18] in perceptive tasks in comparison with a more classic method of direct magnitude estimation [19].

The BWS procedure to apply in the study will follow suggestion presented in [18]. All of the stimuli are presented to each participant. Each trial presented contains 4 stimuli and are all different from each other across the whole experiments. The scoring method used is the value learning algorithm. Despite presenting slightly lower results comparing to other method such as ELO in [18], it shows better resilience to noise in the data, a feature useful for our task. This procedure is implemented through the jsPsych framework [20] and the PDS jsPsych Toolkit [21].

3.3. Pilot Test

A first pilot study was carried on 12 volunteers among colleagues in the lab. To shorten the duration of the experiment, only one level of sharpness is considered : Flat. This pilot study was not carried through a strict controlled process and only shows some tendency that needs confirmation. The first encouraging tendency is the fact that most detectability scores are between the two reference values: the scene with defect condition and no defect condition. The figure also illustrates a positive impact of masks on pleasantness with most of stimuli evaluated having a higher score of pleasantness than the reference scene. Figure 2 illustrates the results obtained in this pilot study. Despite having no measured significance, this figure illustrates the interest of the mask 2 and 3 has : the detectability score increase in both condition, meaning the masking effect is efficient. For thoses masks the pleasantness score also increase, despite increasing the overall sound level. On the other hand mask 4 and mask 1 need to be re-designed before the full scale test. The pilot study suggests mask 4 does not efficiently decrease the detectability of the defect but decrease pleasantness. Mask 1 increase the detectability score even hihger than the reference scene with the defect suggesting this sound is too similar to the defect it is supposed to attenuate.

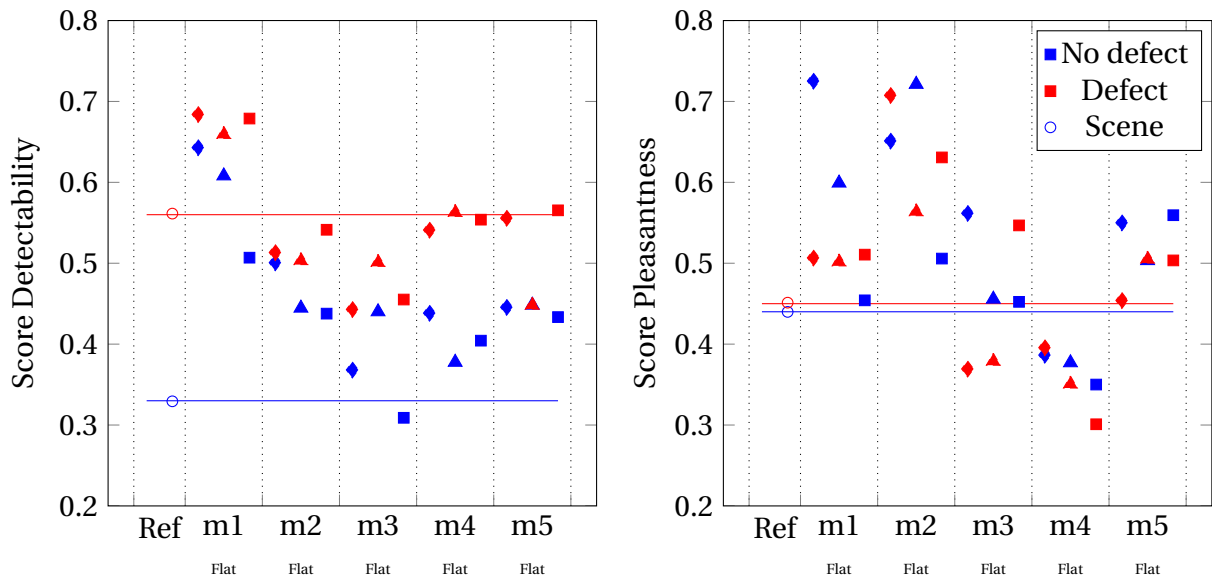


Figure 2: Detectability (left) and Pleasantness (right) score for the designed masks, evaluated by 2 independent group. Scene correspond to the original sound scene without masks. The Loud condition is represented with a diamond, the Neutral condition with a triangle and Quiet with a square.

The expected number of participants for the two experiences are around 20 participants for the detectability experience, and around 50 for the pleasantness experience. The difference in number is explained because the pilote experience (12 volunteers) illustrated a greater variation in subject decision about the more subjective dimension of pleasantness. Indeed, for a given mask we would expect the pleasantness score to be mainly explained by loudness, resulting in a better score for the "Quiet" stimuli, which is not observed on the pilot study.

4. CONCLUSION AND PERSPECTIVE

This on-going work presents in a first hand how the concept of augmented acoustic is applied to electric car cabin comfort improvement. This augmented acoustic concept consists in adding sounds designed for a precisely identified environment : the electric car cabin with a ventilation noise and a whistling noise. In a second hand, this work presents an experimental procedure to evaluate the effect of designed sounds on a given environment. Two tasks of interest are identified : pleasantness and detectability and will be evaluated through a Best-Worst Scaling paradigm.

The first tendencies obtained through this pilot study supports the acoustic augmented concept developped above to treat annoying sound in a scene. Indeed, most of masks tested seem to decrease the detectability score evaluated by participants as well as increasing pleasantness in both condition defect and no defect. Caution is necessary about those tendencies interpretations, specially for subjective task. For instance the pilot study present similar score for the defect and no defect condition in the no mask situation, suggesting the original scene with a defect is rated as pleasant as the original scene without defect.

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