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Comprehensive process for the creation and integration of interior chime sounds for quiet vehicles in China

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ABSTRACT

As new vehicles become quieter and quieter, ambiance, driving-aid, or generally human-machine interface sounds get an increasing importance in the overall interior acoustic environment. This paper describes the application of a comprehensive interior sound design process for quiet personal vehicles in China. This includes a series of necessary steps that are required to meet today's sound requirements for quiet vehicles: aesthetics, drivability, and brand identity: First, initial brainstorming sessions allowed the definition of the brand sound identity and values; then, sounds are created for various functions in the vehicle, on the basis of the defined sound identity and values; The next step consists in the perceptual evaluation of each proposed sound in regards to its intended function in the vehicle; Finally, in light of the results, sounds are selected, and then integrated and calibrated into prototype or series vehicles.

1. INTRODUCTION

Before the recent ages of automobile industry, a strong separation existed within the sounds involved in cars. On the one hand, many sounds were mechanically produced by the physical parts of the car: engine, starter, electric relay of the turn indicator switch, etc. Then, we learned to identify the event, phenomenon, or driving phase associated with each of these sound, over decades of driving vehicles. These sounds now carry a highly informative potential, and strong cognitive links exist between sound and driving experience.

One the other hand, some specific functions required a dedicated sound to be artificially produced: horn, various alarms, such as for unfasten seatbelts, back-up radar, etc. Contrary to the first case, these sounds were not created with any link to the phenomenon or the event targeted. However, another sound notion was considered in the integration of these sounds: perceived urgency. Sounds were often made annoying and quite aggressive to ensure a maximum perceived urgency, while sometimes ignoring potential conflicts, audibility issues, or ill-adapted designs.

Today, this separation does not really exist anymore, as most sounds are now artificially produced by more complex systems, allowing much richer sound synthesis possibilities. These possibilities now push towards more intelligent sound design processes, where the sound

function is taken into account, as well as the cognitive links to specific automotive events, or even aesthetics.

The process of designing sounds, and more specifically chimes and sound alarms, has been thoroughly considered in the scientific literature. An overview of the subject can be found in [1]. Initially, most studies tried to identify which acoustic parameters (pitch, repetition rate, etc.) tend to favor perceived urgency [2,3,4]. Later work rather used a cognitive approach to alarm sounds, by also considering the interaction between the alarm sounds, the user and the context of perception. Therefore, some studies showed that the perception of alarm sounds, and most noticeably the perceived urgency, can be significantly influenced by sound source identification [5], mental workload [6], learning [7], etc. and that ill-adapted alarm sounds can also generate undesired effects, such as dangerous driving behavior for example [8]. In light of all these results, some general rules were defined for the design of alarm sounds [1,9]: unicity of the alarm sound in the listening environment, audibility (face the influence of the background soundscape masking effect), ease of localization and identification, etc.

With this context in mind, a sound creation project was carried out to integrate well designed interior chime sounds into a future car in China. To ensure the best adaptation to target sound functions, the sound design followed a precise and rigorous process described in the following sections.

2. SOUND DEFINITION

The first phase of the project consisted in the definition of the identity of the sounds to be designed. This was done through a brainstorming session, with the purpose of identifying the main values that the future vehicles were supposed to carry. The major idea of this brainstorming session is to group together a wide variety of people involved in the creation of a new vehicle, and gather as much information as possible on how each of them sees what the new vehicle should be and how it should sound. More specifically the brainstorming session may involve people from various departments: product, NVH, marketing, design, systems, etc., engineers, managers, executives, or any other stakeholder. Each of these people must define their vision of the values that the vehicle should demonstrate, the image attached to the brand, the typical scenario of usage, etc.

In order to favor creativity during the brainstorming session, we follow a timed procedure, whose final goal is to build a moodboard. A moodboard is a kind of “patchwork” made of images and keywords (sometimes even sound and video) gathered into a composition describing the values and brand image. This procedure is phased in the following way:

- The brainstorming participants are separated into groups of 4 or 5 people
- Each group should try to answer the 3 following questions:
 - Can you describe the brand’s image in a few words?
 - How do you imagine the new car should be perceived by customers?
 - How do you think the new car should sound?
- To answer these, each group has a limited amount of time (e.g. 30 minutes) to create a moodboard:
 - Find key words to describe the main concepts and ideas
 - Illustrate these concepts and ideas using, images, sounds, videos, voiced imitations, etc.
 - Use these materials to create the moodboard into a slideshow.

As an example, Figure 1 presents one of the moodboards obtained in this project.



Figure 1. Moodboard obtained in the brainstorming session.

3. SOUND DESIGN

According to the outcome of the brainstorming sessions, 3 sound design themes, that are shared by every sound function, were defined:

- High-tech:
 - Reflects the very high level of technologies embedded in modern cars
 - Thought as to provide the driver with a feeling of trust towards the car electronic system
 - Mainly inspired by technology, science and computers
 - Created sounds use modern tech-oriented synthesizers, and small chip-like sounds
 - Uses the extensive imagery of science and computers in the collective mind, coming from the modern culture, such as in many science-fiction movies

- Smart:
 - Smart style is thought as a combination of calm and modern
 - Technology is rather suggested than demonstrated, while the quiet aspect of modern cars is emphasized
 - Combination of complexity and simplicity
 - Also reflects the high intelligence of modern car systems, that allow complete or partial autonomous driving
 - Used sounds are elegant, non-aggressive, while still somewhat technological
- Nature:
 - Reflects the ecological aspect of modern cars, especially EV and HEV, while still containing a discrete technological component
 - It emphasizes the respect for the environment, both in terms of air quality and acoustic quietness and peacefulness
 - Sounds used often natural evocation, such as wind blowing, waves crashing on the beach, animals, ponds and water streams in the woods
 - Many sounds created with wood and string instruments; electronic effects are limited

Then, these 3 themes were used as guidelines to create sound propositions for 20 different sound functions (see Table 2 for a comprehensive list). As a result, 60 sounds were proposed (3 shared themes for each of 20 sound functions).

4. PERCEPTUAL ASSESSMENT

In order to evaluate the sounds designed, they were assessed through a listening test where participants were asked whether each proposed sound would suit their intended function in the vehicle.

Sixty participants (5 women, 55 men) took part in the listening test. They were aged between 20 and 50 (29 between 20 and 30, 30 between 31 and 40, 1 between 41 and 50). All reported having normal hearing.

Each participant assessed 60 sounds, corresponding to 3 propositions to 20 sound functions. Each sound function was specified to the listener so that he could rate between 0 (‘not suitable at all’) and 10 (‘very suitable’) how suitable the sounds were in regard to their intended sound function.

The output data of this listening test takes the form of 20 sets of 60 ratings between 0 and 10 of 3 proposed sounds. First, individual data is analyzed in order to compare the ratings of each participant, and identify groups of participants with similar ratings or outliers. Second, the variance of the data is analyzed in order to compare ratings of the different sound functions and the different design themes. Finally, sounds are selected on the basis of the results of the analysis.

4.1 Individual analysis

The individual analysis consisted in calculating a correlation coefficient between the ratings of each pair of participants. Figure 2 presents the obtained correlation matrix. In this figure, the brighter a cell is, the higher the correlation coefficient between the corresponding pair of participants is. This allows us to identify possible outliers as rows (or columns, since the matrix is symmetric) which are significantly darker than the others.

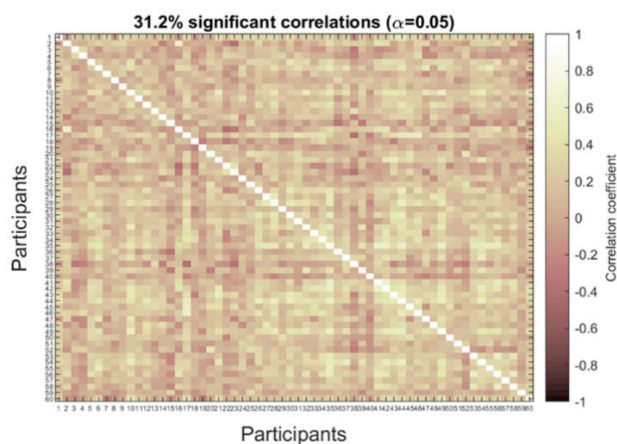


Figure 2. Participant correlation matrix. A brighter cell corresponds to a higher correlation coefficient (color scale on the right of the matrix).

This matrix shows a moderate overall agreement between participants, as only 31.2% of correlations coefficients are significant ($p < 0.05$). This means that participants tend to rate sounds quite differently than the others. However, the observation of the matrix does not reveal strong discrepancies of ratings between the participants (except maybe some slight differences for some participants, e.g. 16, 18, 38, 40, ...).

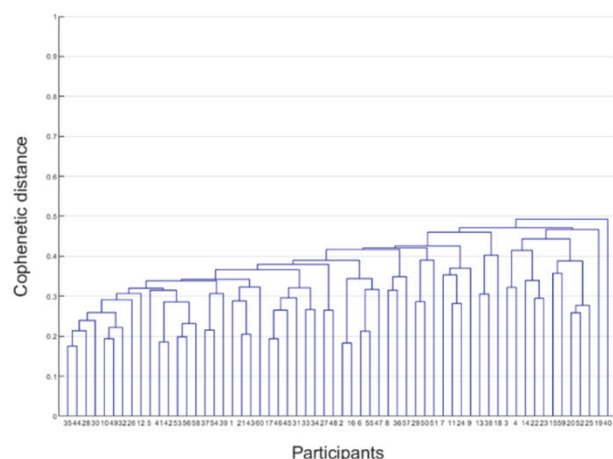


Figure 3. Dendrogram presenting the proximity between participants' ratings. The smaller the cophenetic distance is between 2 participants, the more correlated their ratings are.

In order to confirm this, a cluster analysis with the average method was performed on this matrix. The resulting dendrogram is displayed on Figure 3. This only

confirms slight discrepancies of participant 38's and participant 40's ratings (far right of the dendrogram), but no distinct rating trends (i.e. groups of participants) is revealed.

Finally, to conclude on the impact of identified participants with possible divergent ratings, their influences on the departure from normality of the rating distributions was assessed. With all 60 participants, the hypothesis of normality is not rejected for 62 % of the distributions according to Jarque-Bera tests. Removing either or all of the previously identified outliers does not increase this percentage. As a conclusion, none of the participants' sets of ratings stands out enough of the others to be removed from the panel; all 60 participants are kept for the subsequent analysis.

4.2 Factor analysis

In order to compare rating differences due to either sound function or design theme, a 2-way repeated-measure analysis of variance (ANOVA) was applied on the data, using a 20*3 design of experiment (20 sound functions, 3 themes). The obtained results are displayed in Table 1. Both factors have significant effects, as well as their interaction.

Effect	Sum of squares	Degrees of freedom	Mean square	F	p	η^2
Theme	105.2	2	52.6	16.21	<.001	1.05%
Error (Theme)	382.9	118	3.24			
Function	684.7	19	36.04	14.24	<.001	6.84%
Error (Function)	2835.8	1121	2.53			
Theme* Function	638.6	38	16.81	9.23	<.001	6.38%
Error (Theme* Function)	4083.9	2242	1.82			

Table 1. ANOVA table.

This table also shows that the effect size of factor theme is much lower than those of factor Function and the interaction. ($\eta^2 = 1.05\%$, vs. $\eta^2 = 6.84\%$ and $\eta^2 = 6.38\%$). The effects are illustrated on Figure 4, Figure 5 and Figure 6. Figure 4 shows the average ratings (all functions confounded) of the 3 design themes. This figure confirms that the effect size is very small, although it is significant, and post-hoc Dunn-Bonferroni tests show that Nature has a significantly better score than both other themes, even though this difference is small in comparison to the rating range 0-10, and that there is no significant difference between themes High-tech and Smart.

Figure 5 shows the average ratings (all themes confounded) of the 20 sound functions. According to post-hoc Dunn-Bonferroni tests, significantly better ratings were given to Out of hand, Lane departure, Rear tailgating, Rear & Front radar, Welcome and Key-on sounds. On the contrary, IACC sounds generally got the worst ratings (except IACC on), and Touchscreen and, to a lesser extent, Fault alarm got worse score than the other sound functions.

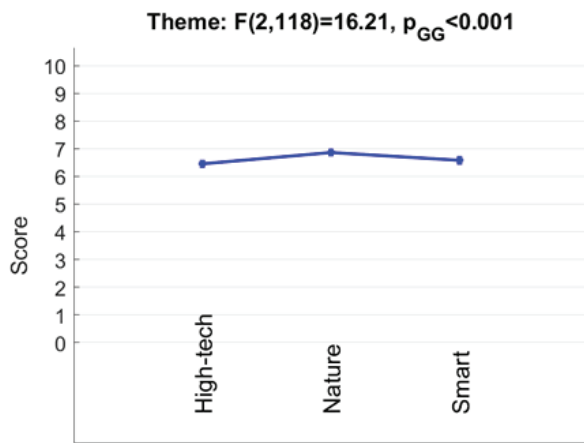


Figure 4. Average score for each of the 3 design themes.

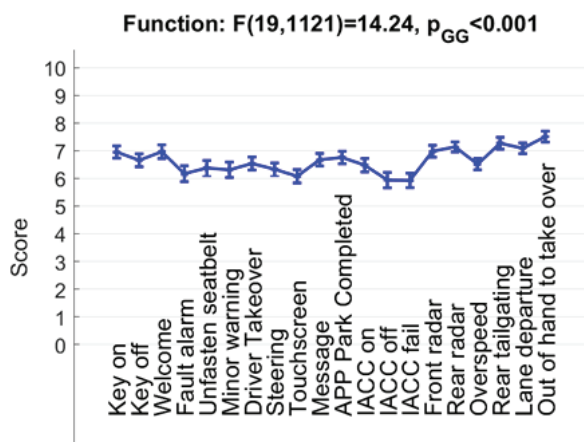


Figure 5. Average score for each of the 20 sound functions.

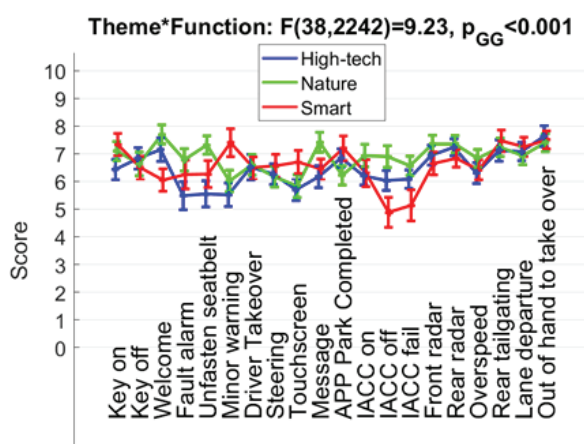


Figure 6. Average score for each of the 3 design themes and each of the 20 sound functions.

Figure 6 shows the average ratings for each sound function and each design theme. The significant interaction indicates that the ratings of the 3 themes depend on the sound function. More specifically:

- Nature theme is best preferred for several sound functions: Welcome, Fault, Seatbelt, Message,

and IACC sounds (and slightly worse ratings for APP Park Completed);

- Smart theme is best for some sounds: Minor warning and Touchscreen, and worst for Welcome and IACC off and fail

High-tech is not preferred for any function, and even worst for Key-on, Fault, Seatbelt, and Minor Warning.

4.3 Final sound selection

Final sound selection for each function was done in light of the results of the analysis (see Table 2):

- As it receives the best scores for many functions, and does not receive significantly lower scores for the others, Nature theme should be generally preferred throughout the whole set of sounds, in order to maintain sound consistency between sound functions
- As exceptions, for Minor warning, Touchscreen, and APP Park Completed, Smart theme sounds should be used instead of Nature, as they got significantly better ratings, and do not really break the harmony of the other Nature theme sounds
- High-tech theme sounds should not be considered any further

Sound function	Selected theme	Alternative choice
Key on	Nature	Smart
Key off	Nature	
Welcome	Nature	
Fault alarm	Nature	
Unfasten seatbelt	Nature	
Minor warning	Smart	Nature
Driver Takeover	Nature	
Steering	Nature	Smart
Touchscreen	Smart	Nature
Message	Nature	
APP Park Completed	Smart	
IACC on	Nature	
IACC off	Nature	
IACC fail	Nature	
Front radar	Nature	
Rear radar	Nature	
Overspeed	Nature	
Rear tailgating	Nature	Smart
Lane departure	Nature	Smart
Out of hand to take over	Nature	

Table 2. Final sound selection.

5. IN-VEHICLE FINE TUNING

The final step of the project was to adjust sounds in the target vehicle. It often happens that created sounds, when

designed in the office on desktop systems with good-quality speakers and audio setup in general, sound quite differently when played in the vehicle, for 2 major reasons:

- Different qualities of the vehicle audio setup and speakers, which can change the frequency content, and in some cases even deteriorate the quality of the sounds
- Acoustic response of the car cabin, which can also alter the frequency content, add modal peaks or notches in the spectrum, and change the overall spatial aspect of the sounds.

For these reasons, it is necessary to perform measurement and listening sessions once the sounds are integrated into the audio system of the vehicle. This is mainly done in 3 steps:

1. Correction of the frequency response measured at the driver position (including both the system and speaker frequency response and the car cabin frequency response). Here, the frequency response was measured by playing a reference noise (pink noise) through the vehicle audio system, and recording the acoustic signal at the driver position. This allowed us to build a correction filter using a parametric equalizer, with peaks and notches set to compensate the non-flat measured spectrum (see Figure 7).



Figure 7. Correction of the frequency response of the car cabin.

2. Optimization of the stereo panning, or more generally multichannel panning, to get the best effect at the driver position. Here, the level of each output channel of the vehicle audio system was changed so that the stereo image would be set at the front of the driver (for sound functions where stereo effects are not included, see Figure 8). For more complex sounds with stereo effects, a finer tuning of each channel was done by ear, in order to keep the original stereo effects.



Figure 8. Multichannel panning adjustment.

3. Add or improve spatial effects (reverberation, etc.). Finally, reverberation was artificially added to the sounds in order to get a better spatial impression when playing the sounds (see Figure 9). Indeed, car cabins are most often absorbent environments, which tend to rub out the feeling of space originally intended when designing the sounds.



Figure 9. Creation of an artificial space feeling through the addition of reverberation.

As a final validation step, a short listening session was conducted in vehicle, in order to get feedback from several people about the quality of the conducted fine tuning. Feedback was quite good, and the resulting setup was deemed satisfying for final integration.

6. CONCLUSION

This project aimed at creating a new set of interior sounds to be integrated into series of future vehicles in China. For this, a comprehensive sound design project was used. The first step of this project was dedicated to the definition of

the desired sound identity for the new generation of vehicles. This was done mainly through a brainstorming session with people from various background (engineer, manager, marketing, decision-makers, etc.) whose aim was to provide audiovisual materials to capture the main ideas and values that the new vehicle sounds should carry. In light of these results, 3 sets of sounds were designed for 20 sound functions, each with a common design theme: High-tech, Smart, and Nature. Then, these 3 sets of sounds were assessed perceptually in a listening test, whose results made it possible to select the best suited sounds for each sound function. Finally, these sounds were integrated into a prototype version of future vehicles, in order to finely tune each sound played through the actual multimedia system of the future vehicle. The full sound design procedure applied here proved to be very efficient in creating future vehicle sounds that are at the same time aesthetical, functional, and harmonized.

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