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Rotary Engine Essence Utilization for In-Car Sounds Driven Design

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ABSTRACT[*]

In recent years, the widespread adoption of electric vehicles (EVs) has led to a reduction in engine noise emitted outside vehicles. However, engine sounds are important for drivers to perceive acceleration. Therefore, the primary objective of this study is to identify the appropriate acceleration sound for EV operation. This study aims to evaluate whether synthesized sounds exceed the characteristics of actual engine sounds and explore the types of sounds that align with brand image. Specifically, this study compared the impression of the engine sound of a rotary car with three types of synthesized sounds based on the actual engine sound. Through this research, it is possible to explain the differences between the in-vehicle engine sounds and synthesized sounds, which could contribute to establishing a brand image through sound.

Keywords: *in-car sounds driven design, synthesized sound, realistic evaluation, SD method, preference*

1. INTRODUCTION

What defines a good automobile? One critical factor is driver comfort, which is examined from the perspective of sound quality. Sound quality can be considered as the fulfillment of driver expectations; if the driving sound of a purchased vehicle falls short of these expectations, it can be perceived as poor sound quality. The coauthor, Mitsuda, is a renowned composer in Japan, known for his work on anime and video game music. In these fields, the sounds must exceed user expectations. For instance, in anime and manga, sound design often demands representations beyond what exists in reality, such as firearm sound effects, which are more stylized than actual gunshots.

Moreover, within the realm of digital art, computer-generated (CG) techniques are considered to be as significant as traditional hand-drawn or stop-motion animation techniques, and they play, an indispensable role in artistic creation [1]. In the driving context, the adoption of electric vehicles (EVs) has increased recently. To enhance driver focus, many EVs generate synthetic acceleration sounds through speakers, which are often based on traditional engine noises. Previous studies have demonstrated that both objective and subjective evaluations highlight the significance of acoustic design in determining the effectiveness and accuracy of Active Sound Generation System (ASGS) in electric vehicles (EVs) [2]. Furthermore, research has investigated the correlation between emotional attributes and acoustic parameters that take engine revolutions per minute into account [3], and other work has proposed objective sound quality indices for assessing the "sportiness" of engine sounds [4]. However, from the perspective of composers specializing in anime and game music—an artistic viewpoint—there is a demand for sound expressions that exceed conventional expectations.

By conducting psychological evaluations of these sound expressions and analyzing their generation methods, this study aims to contribute significantly to both the automotive industry and acoustic research.

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2. EXPERIMENTAL PREPARATION

In this experiment, adjective pairs necessary for conducting impression evaluations of actual engine sounds and synthesized sounds mimicking them using the semantic differential (SD) method were collected. First, participants were made to watch a driving video [5] to investigate adjectives that express the "sporty characteristics" of a sports car. The experiment was conducted with 13 participants, aged between their 20s and 50s, who were members of the research laboratory. Among the collected adjectives, the 20 most frequently mentioned ones were selected for use in the SD method experiment. Tab. 1 shows the 20 adjective pairs used in the experiment. For the adjective pairs shown in Tab. 1, counterparts of the 20 collected adjectives were carefully selected to avoid forming negations.

Table 1. Adjective pairs obtained from the experiment

Heavy	Light
Heavy	Light
Sporty	Static
Rough	Delicate
Strong	Weak
High	Low
Noisy	Quiet
Cool	Plain
Luxurious	Cheap
Rumbling	Smooth
Aggressive	Gentle
Muffled	Clear
Large	Small
Makes you want to travel	Makes you want to relax
Piercing	Calm
Frightening	Reassuring
Resonant	Non-resonant
Dry	Damp
Mechanical	Human-like
Dynamic	Still
Brave	Reserved

3. EXPERIMENTAL ENVIRONMENT

The experiment was conducted in an anechoic chamber at the Hiroshima City University. A sound presentation was performed using an Equalizer (labP2-V1 (HEAD acoustics and headphones (k812 (AKG)).

4. EXPERIMENTAL METHOD

This experiment evaluated the perceptual impressions of actual engine sounds and artificially synthesized sounds created by a sound designer using the SD method. The experimental interface used in this study is illustrated in Fig. 1. The sound designer responsible for creating the synthesized sound sources was Mr. Mitsuda, who has been actively composing music for various video games and anime, including the Chrono Trigger. The experiment was conducted with 16 automotive engineers (all males, aged 30–60 years) and nine university students (four males, in their 20s) as participants.

Figure 1. Experimental screen

5. EXPERIMENTAL RESULTS

5.1 Evaluation by Engineers

The results of the factor analysis are shown in Tab. 2. Five factors were extracted in this experiment (Tab. 2), and they were interpreted as follows: factor 1: sportiness; factor 2:

roughness; factor 3: heaviness; factor 4: metallic quality; and factor 5: loudness.

Table 2. Factor loadings based on engineers' evaluations

Adjectives＼Factor	1	2	3	4	5
Sporty	0.906	-0.257	0	0.182	-0.034
Dynamic	0.902	-0.094	-0.115	-0.027	0.118
Cool	0.886	-0.171	-0.189	-0.284	-0.012
Brave	0.771	0.13	-0.012	0.047	0.035
Strong	0.594	0.101	0.163	-0.064	0.303
Aggressive	0.492	0.357	0.142	0.319	-0.075
Noisy	0.378	0.299	0.042	0.332	0.135
Makes you want to travel	0.316	-0.308	-0.051	-0.145	-0.139
Rumbling	0.287	0.939	0.027	-0.155	-0.434
Rough	-0.119	0.882	0.017	-0.036	0.081
Luxurious	0.247	-0.662	0.334	-0.256	-0.018
Heavy	0.073	-0.17	1.001	0.061	-0.049
Dry	0.114	0.055	-0.654	-0.075	0.019
Muffled	-0.175	0.316	0.535	-0.124	0.089
Frightening	-0.017	0.21	0.267	0.813	0
Mechanical	-0.022	-0.149	-0.02	0.808	-0.088
High	0.12	-0.101	-0.42	0.573	0.078
Piercing	0.024	0.255	-0.329	0.535	0.023
Large	0.313	0.3	0.029	-0.199	0.556
Resonant	0.151	-0.138	-0.041	0.015	0.526

The scores for each sound source were compared for five factors. Figs. 2–4 show score comparison graphs for the factors with higher contribution rates. In these graphs, impressions become stronger as the values extend outward, whereas inward values indicate the stronger presence of opposing impressions. The "midpoint" marked in the graphs represents a score of 0, indicating a neutral impression with no clear tendency toward either side.

Fig. 2 compares the scores of each sound source for factor 1, sportiness. The results indicated that pseudo-sound sources 1 and 3 exhibited similar impression tendencies regarding sportiness. By contrast, the real engine sound demonstrated a distinct impression that differed from the other three sound sources.

Fig. 3 compares the scores of each sound source for factor 2, roughness. Similar to Fig. 2, pseudo-sound sources 1 and 3 show a similar tendency, whereas the real engine sound exhibits a distinct impression that differs from the other three sound sources.

Fig. 4 compares the scores of each sound source for factor 3, heaviness. Similar to the results shown in Figs. 2 and 3, the comparison shows similar tendencies for pseudo-sound sources 1 and 3, whereas the real engine sound demonstrates a distinct impression. In addition, pseudo-sound source 2 showed a score close to the midpoint, indicating that its impression was not clearly evaluated.

The factor scores for all sources are shown in Fig. 5.

Fig. 5 shows the factor scores for each sound source across all factors. The real engine sound was evaluated as having sportiness and roughness, as well as being perceived as light and metallic (Fig. 5). Furthermore, pseudo-sound sources 1 and 3 were evaluated as heavy and non-metallic, while pseudo-sound source 2 was evaluated as lacking sportiness and roughness and was perceived as a light sound.

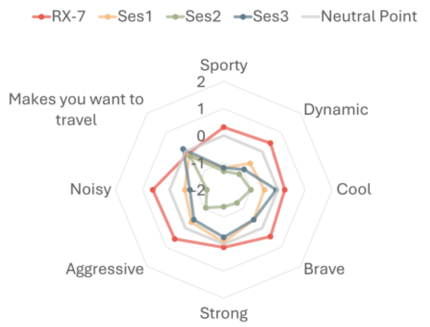

Figure 2. Comparison of sound sources for sportiness

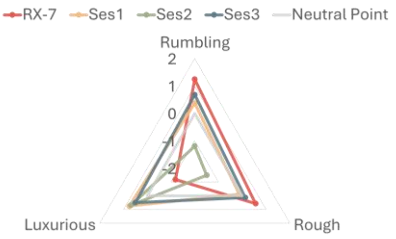

Figure 3. Comparison of sound sources for roughness

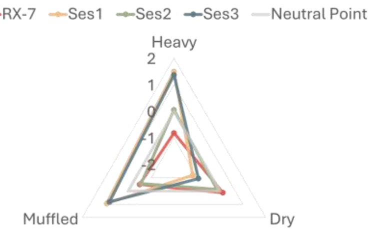

Figure 4. Comparison of sound sources for heaviness

Figure 5. Comparison of sound sources across all factors (by engineers)

5.2 Evaluation by Students

The results of the factor analysis of students are shown in Tab. 3. In the case of students, six factors were extracted (Tab. 3). These factors were interpreted as follows: factor 1: metallic quality; factor 2: sportiness; factor 3: strength; factor 4: roughness; factor 5: pitch; and Factor 6: heaviness.

Table 3. Factor loadings based on students' evaluations

Adjectives＼Factor	1	2	3	4	5
Sporty	0.906	-0.257	0	0.182	-0.034
Dynamic	0.902	-0.094	-0.115	-0.027	0.118
Cool	0.886	-0.171	-0.189	-0.284	-0.012
Brave	0.771	0.13	-0.012	0.047	0.035
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Luxurious	0.247	-0.662	0.334	-0.256	-0.018
Heavy	0.073	-0.17	1.001	0.061	-0.049
Dry	0.114	0.055	-0.654	-0.075	0.019
Muffled	-0.175	0.316	0.535	-0.124	0.089
Frightening	-0.017	0.21	0.267	0.813	0
Mechanical	-0.022	-0.149	-0.02	0.808	-0.088
High	0.12	-0.101	-0.42	0.573	0.078
Piercing	0.024	0.255	-0.329	0.535	0.023
Large	0.313	0.3	0.029	-0.199	0.556
Resonant	0.151	-0.138	-0.041	0.015	0.526

The scores for each sound source were compared for six factors. The score comparison graphs for factors with higher contribution rates, up to factor 3, are shown in Figs. 6–8. The interpretation of these graphs follows the same method as those shown in Figs. 3–5.

Fig. 6 shows a comparison of the scores for each sound source with respect to factor 1 (metallic quality). As shown in Fig. 6, the evaluation of metallic quality is completely different across all sound sources, indicating distinct perceptions of metallicity for each source.

Fig. 7 compares the scores for each sound source with respect to factor 2, sportiness. As shown in Fig. 7, the three pseudo-sound sources exhibited similar tendencies, whereas the real engine sound showed a distinct trend that differed from the other three sound sources.

Fig. 8 compares the scores for each sound source for factor 3 (strength). The real engine sound was evaluated as having a strong impression of being loud, whereas pseudo-sound source 1 shows a minimal evaluation of strength (Fig. 8). Pseudo-sound source 2 had a strong impression of being small and weak, while pseudo-sound source 3 was primarily perceived as small in terms of strength.

The factor scores for all sources are shown in Fig. 9.

Fig. 9 shows the factor scores for each sound source across all factors. The real engine sound was perceived as having a strong metallic quality, being sporty, powerful, and slightly high-pitched (Fig. 9). Pseudo-sound sources 1 and 3 were perceived as having a somewhat heavier impression, whereas pseudo-sound source 2 was evaluated as smooth and light.

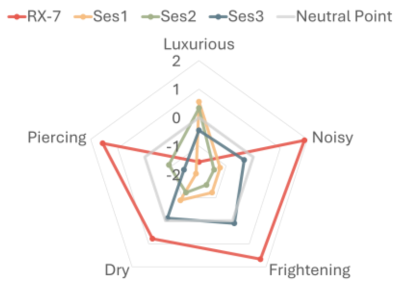

Figure 6. Comparison of sound sources for metallic quality

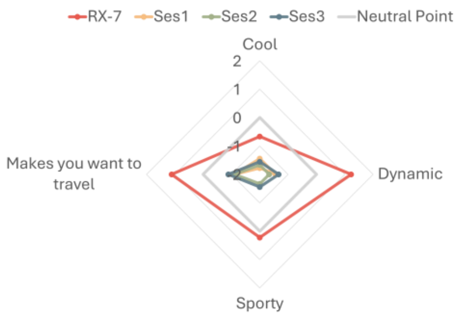

Figure 7. Comparison of sound sources for sportiness

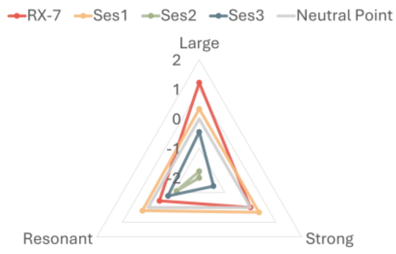

Figure 8. Comparison of sound sources for strength

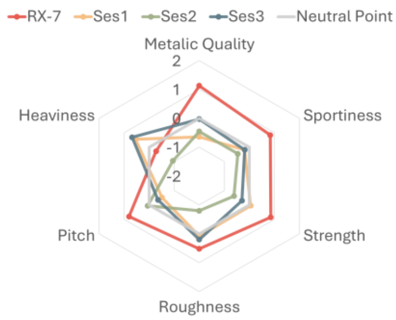

Figure 9. Comparison of sound sources across all factors (by students)

5.3 Preference Evaluation

This section presents the results of sound source preference. Fig. 10 illustrates engineers' preferences for different sound sources.

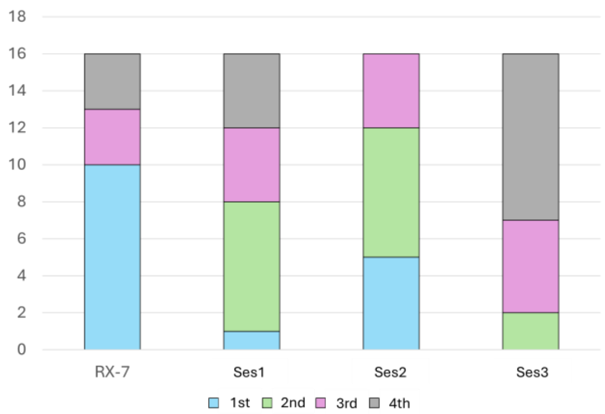

Figure 10. Investigation of preferred sound sources

5.4 Evaluation of Realism

Here, we present the results of the sound sources identified as realistic. Fig. 11 illustrates the responses of engineers regarding the sound sources they perceived as real engine sounds, specifically those they identified as RX-7 engine sounds.
Fig. 11 shows that most participants perceived RX-7 as the most realistic, followed by Synthesized Sound 2, and then Synthesized Sound 1.

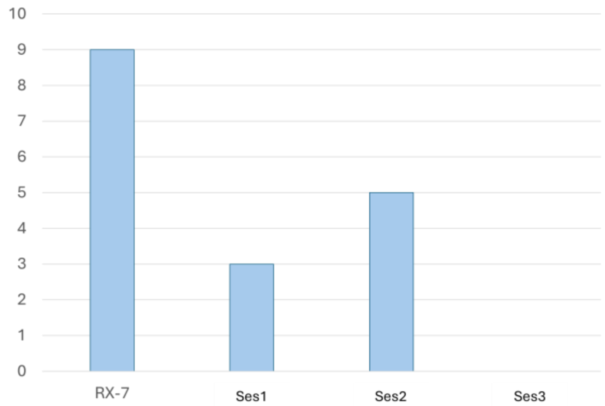

Figure 11. Engine sounds perceived as realistic

6. DISCUSSION

In this experiment, a perceptual evaluation of each sound source was conducted. However, some synthesized sound sources exhibited similar tendencies across certain factors, and some sound sources did not elicit a distinct impression. This phenomenon is likely attributable to the absence of road noise, which is present in actual engine sounds and leads to similar auditory impressions. Consequently, it is considered that the RX-7, which includes road noise, evoked a significantly different impression.
Additionally, this experiment revealed that impressions varied significantly depending on whether the participants were engineers or students. Engineers familiar with engine sounds in their daily work are likely to discern subtle differences in sound characteristics. By contrast, students may not be accustomed to distinguishing engine sounds in detail. In the student evaluation, a clearer distinction in auditory impression was observed between RX-7 and the synthesized sound sources.
Furthermore, Fig. 10 shows that the largest number of participants rated the real engine sound as their most preferred. However, this result alone does not indicate that

RX-7 is the best sound source. This is because while the number of participants who ranked synthesized sound source 2 as their top preference was lower than those who chose RX-7, fewer participants ranked it fourth compared RX-7.

Therefore, it is necessary to conduct further experiments to verify these results. In future studies, instead of ranking preferences sequentially from first place, participants should be allowed to select multiple sound sources that they perceive as preferable. This approach provides a more comprehensive understanding of the genuinely preferred sounds. Furthermore, road noise must also be considered. According to Mitsuda, the low-frequency components of road noise contribute to the perception of a car's luxury.

Fig. 11 shows that the majority of participants identified RX-7 as the most realistic engine sound, followed by Synthesized Sound 2 and then Synthesized Sound 1. The reasons for these preferences will be investigated in future studies. Even after excluding the absence of road noise in the synthesized sounds during the impression evaluation in this study, Synthesized Sound 2 was often associated with the opposite impression of RX-7, whereas synthesized sound 1 received little evaluation in terms of its impression. Therefore, the impressions that were not captured by the adjectives used in this study may have influenced these results.

7. CONCLUSION

This study revealed a perceptual difference between real RX-7 engine sounds and synthesized sound sources. When the participants were asked to identify the most realistic sound, the majority selected RX-7, likely because the synthesized sounds did not include road noise, making them less perceivable than real engine sounds. The results of the impression evaluation may have been influenced by the presence or absence of road noise.

In future research, we plan to conduct additional experiments that incorporate road noise into synthesized sound sources. Through further impression evaluations and preference assessments, we aimed to establish a correlation between the desired auditory impressions and engine sounds preferred by drivers.

8. REFERENCES

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