



Perception of tire-pattern noise

Takeo Hashimoto¹

Seikei University

3-3-1 Kichijoji Kitamachi Musashinoshi, Tokyo 180-8633 Japan

Shigeko Hatano²

Seikei University

3-3-1 Kichijoji Kitamachi, Musashinoshi, Tokyo 180-8633 Japan

ABSTRACT

Due to the increase of electric motor cars for preventing spread of carbon dioxide, noise atmosphere inside the car compartment is more important for the perception of tire-pavement noise. This paper describes the impression of pattern noise created by the tire thread pattern under real running condition. Our impression on tire-pattern noise is more prominent if the peak level of the pattern noise is higher together with its frequency location is in certain mid frequency and width of the peak is wider. This paper deals with our impression on tire pattern noise how our impression varies with its peak level and frequency location.

1. INTRODUCTION

In order to reduce atmospheric temperature due to the increase of carbon dioxide, grovel movements for introducing electric motor cars are now in progress. Due to this happening, car interior noise inside the car compartment becomes more quieter than before and is more stressed by tire noise instead of conventional powertrain noise because of the quietness of an electric motor under real driving. This paper deals with tire pattern noise created by relative movement of tires and smooth road surface. The tire patterns cut on the tire surface are intended to prevent and to reduce slip under wet road surface. In this study, 3 kinds of tires are delt for perception, namely, entry, luxury and winter tires, each category belongs to car type and season for use during winter. What we have done for perception of tire pattern noise is that, at first, we have extracted background noise profile from the recording signal of tire pattern noise, then several prominent components of tire pattern noise are decided by the subjective experiment through hearing test. In this experiment, subjects are asked to point out if subject can hear the component signal or not by his/her decision. If many subjects can hear the specific component, then that component is the possible candidate for evaluation.

¹ hashimot@st.seikei.ac.jp

² hatano@st.seikei.ac.jp

2. BACKGROUND NOISE PROFILE

Background noise profiles are extracted by introducing moving average on the frequency domain by removing local small peaks as shown in Fig. 1.

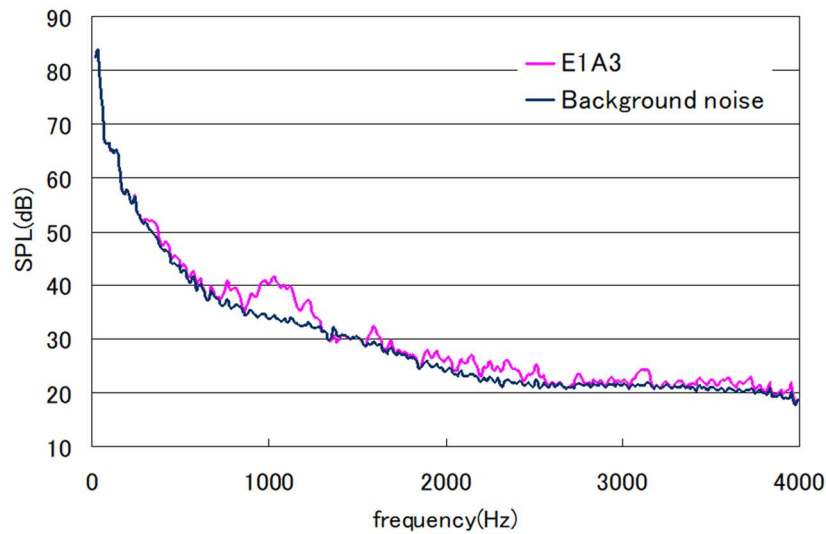


Figure 1: Tire pattern noise on frequency domain and its background noise.

In this figure, blue line indicates background noise profile and red line indicates tire pattern noise profile. The next stage is to determine the numbers of annoyance components of tire pattern noise. For this, each of the pink components are eliminated by the digital filter technique step by step for subjects to indicate if he/she can detect the component sound by presenting original tire pattern noise and similar noise that eliminated specific component. If subject can detect the sound component that eliminated from the original, then he/she can detect difference between the two sounds.

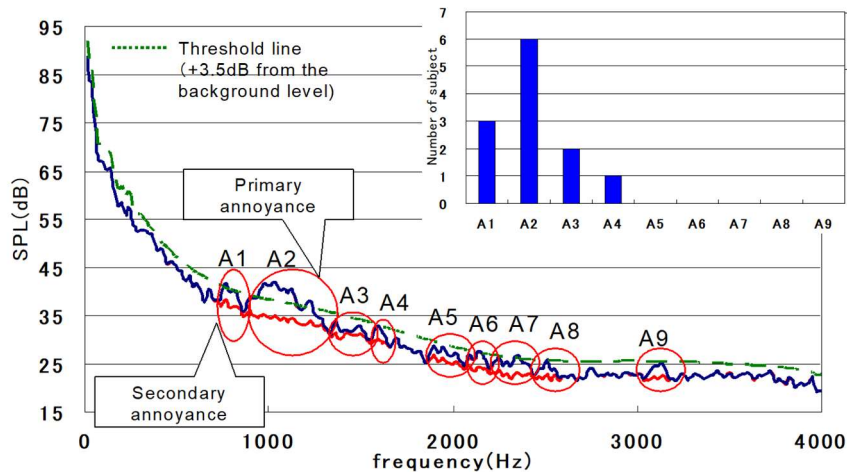


Figure 2: Tire pattern noise profile and components detected.

In this experiment, total of 7 subjects are participated for detection of each component sound. Judging from this figure, A2 component was detected most by 6 subjects and second candidate is A1 component. So, for this sound, A2 is primary component and A1 is secondary component for the perception of tire pattern noise. The rest are not selected by many subjects. The results are similar for other tire pattern noise. So, we have decided to pick up two components most for tire pattern noise perception and other components are eliminated down to the background noise level by applying digital filter technique.

3. EVALUATION OF PROMINENT AND SECONDARY COMPONENT SOUND USING THEIR VARIATIONS

For the evaluation of tire pattern noise for the creation of model for prediction, prominent component and secondary component are varied their peak level, frequency band width and location of frequency as shown in the following figure.

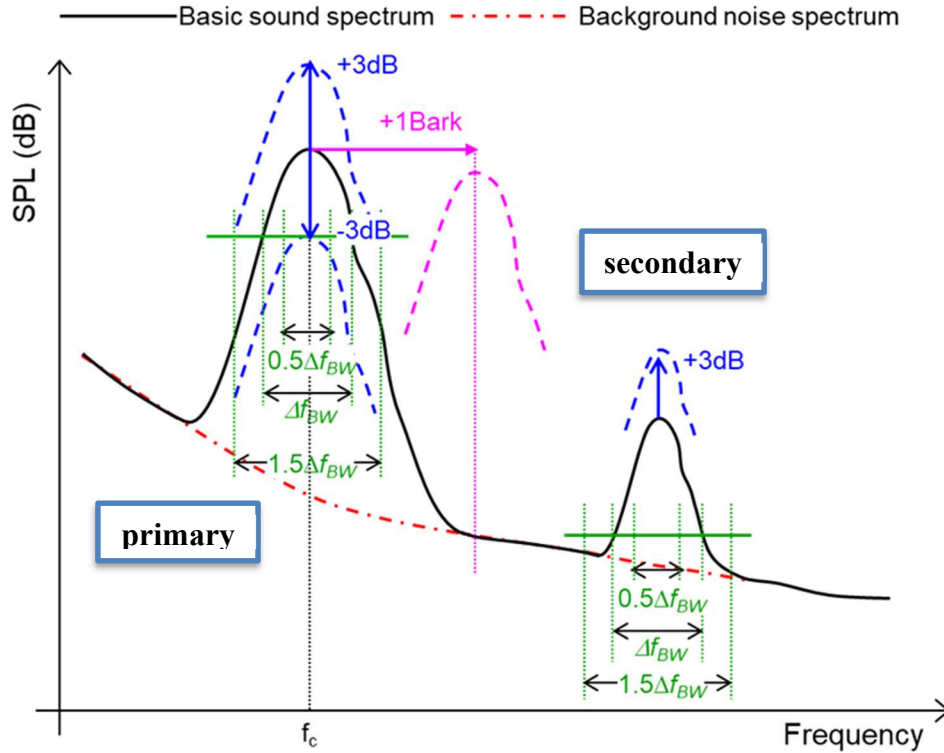


Figure 3: Variation of primary component and secondary component.

As shown in Figure 3, primary component is varied its peak level three steps, namely, +3dB, 0dB, -3dB and frequency bandwidth are varied three steps, namely, original bandwidth at the 3dB down point from the original peak and the increase of 1.5 bandwidth and decrease of 0.5 bandwidth. Frequency location is moved from the original to +1.0 Bark bandwidth. The secondary component is varied its peak level from the original to +3dB and frequency bandwidth is varied as is the same for primary peak.

3.1. Test method

Magnitude estimation method is introduced for evaluation of sound by using PC screen. Subjects are asked to apply suitable score ranged from 1 to 50 by moving the slide scale on the PC screen as shown in Figure 4. The number of subjects participated this experiment are 18 that are mixture of male and female aged between 22 to 60 with normal hearing.



Figure 4(a): Evaluation sheet

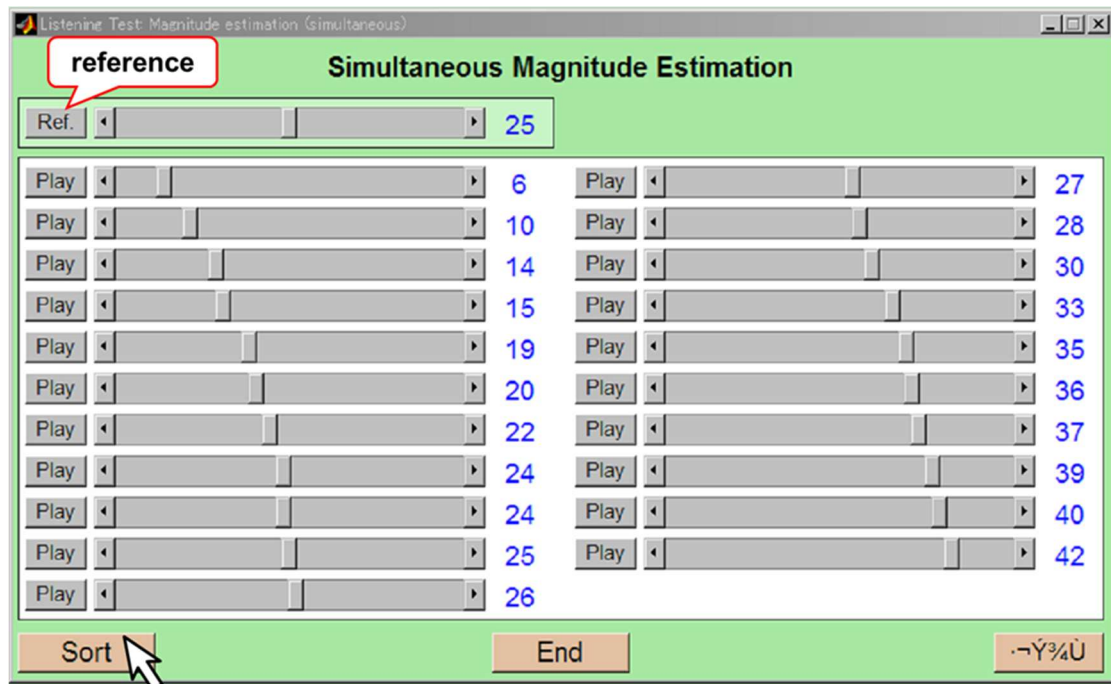


Figure 4(b): Evaluation input screen on PC.

The first line of the paragraphs should be indented by 0.5 cm.

3.2. Test sound

Sounds to be evaluated are the tire pattern noise of entry category running on the road at the constant speed of 80km/h and with different tire surface cutting.

3.3 Test result

The result is shown in the following figure and the regression analysis using explanatory variables including frequency positions of primary and secondary annoyance component, those of frequency bandwidth, peak level.

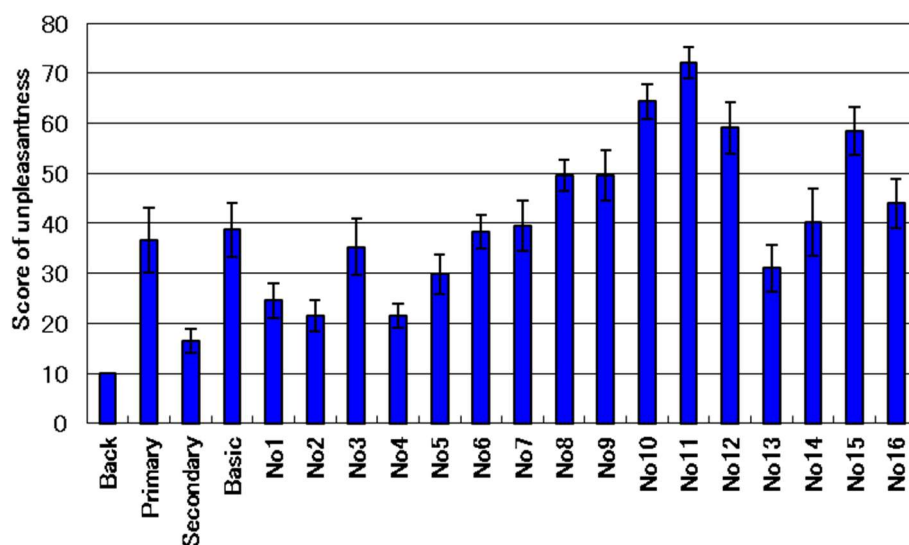


Figure 5: result of evaluation for E1 sounds with variations.

Table 1: result of multiple regression analysis for E1 sound.

Variables		RC	t value
P.Level	Constant	11.668	2.429
	Ori	15.388	4.531
P.Bandwidth	+3dB	35.627	9.084
	Ori	8.905	2.622
S.Level	3/2 Δf	17.560	4.477
	+3dB	3.462	1.248
S.Bandwidth	Ori	1.474	0.434
	3/2 Δf	1.808	0.461
P.Frequency location	+1Bark	5.168	1.864

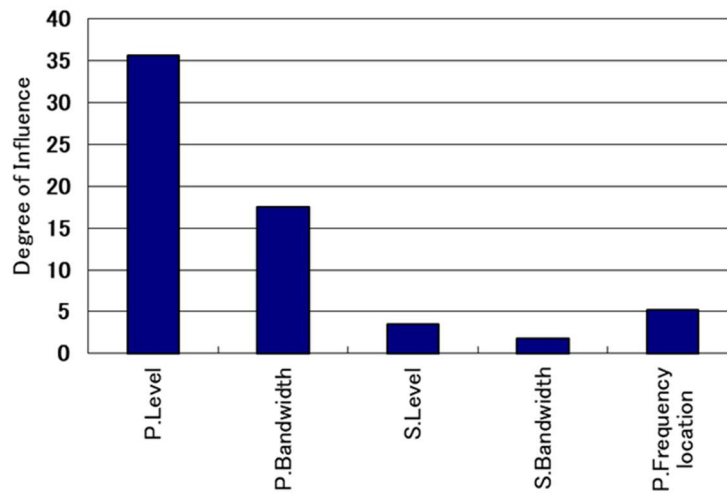


Figure 6: Degree of contribution on each explanatory variable.

As is shown in Figure 6, the contribution is most for peak level variation of the primary annoyance component is the largest and the second contribution is that of the band width. The rests are marginal contributions. This tendency is always the same for other sounds for evaluation, Figure 7.

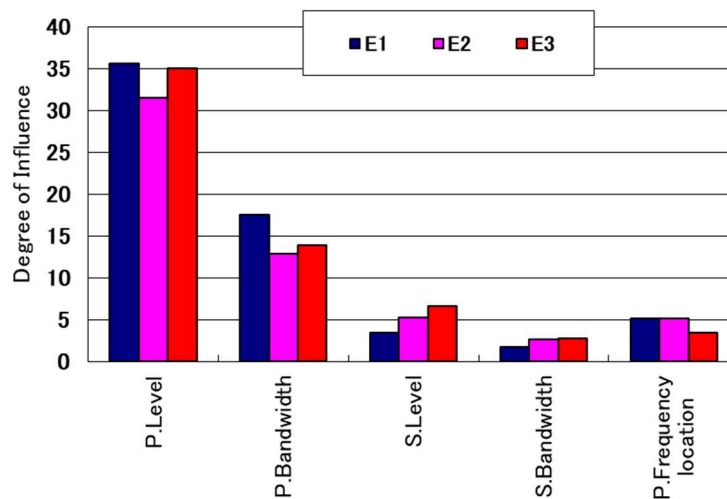


Figure 7: Degree of contribution on each explanatory variable for the different group of sounds.

From this result, the sound variations to be evaluated for annoyance should be better to limited to the variation of primary annoyance component alone provided that the primary component is prominent

component compared with the secondary component. If this could be true, then the variation of annoyance component is shown in the following figure.

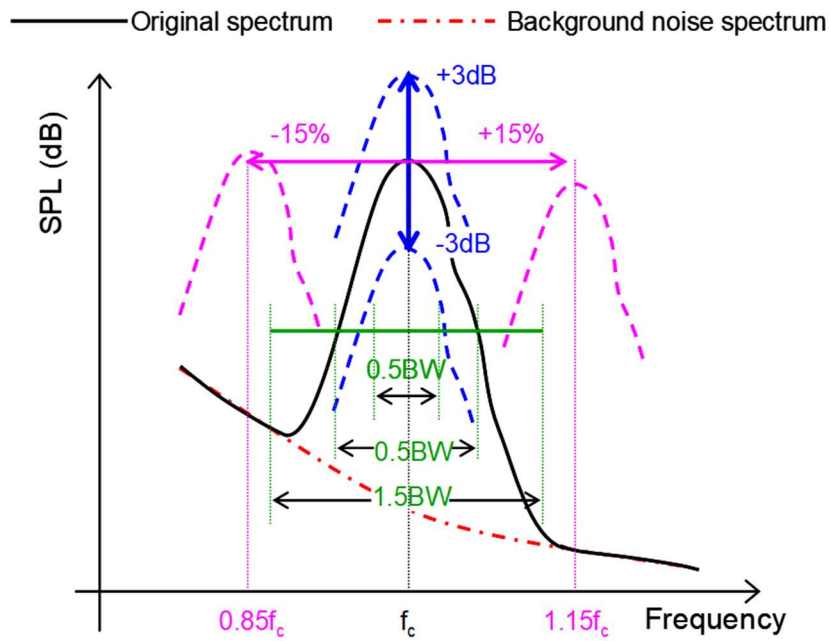


Figure 8: Variation of primary annoyance component.

The variation of test sounds is shown in figure 8. The variations are peak level variation, i.e. original level $\pm 3\text{dB}$, frequency location, i.e. original location $\pm 0.15f_c$ and variation of frequency bandwidth, i.e. original bandwidth, 0.58times of the original and 1.58times the original.

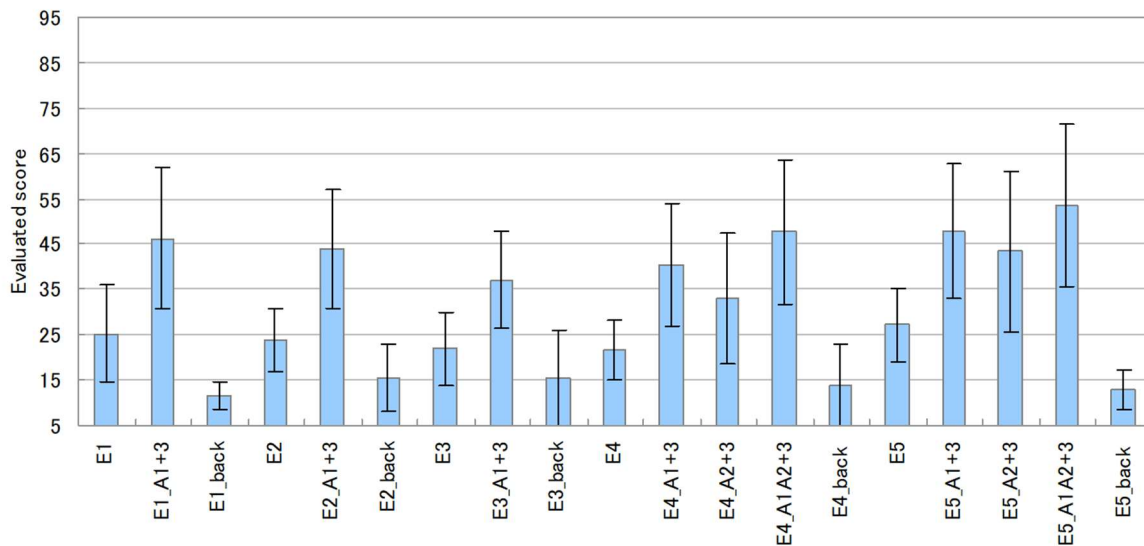


Figure 9: Evaluation of tire pattern noise (Entry category)

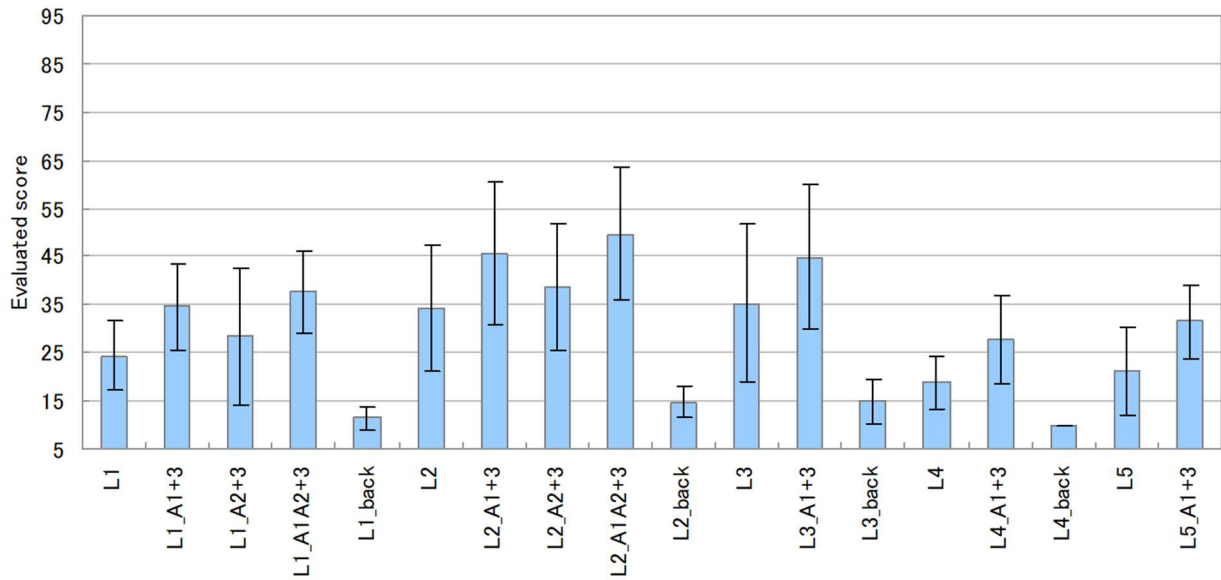


Figure 10: Evaluation of tire pattern noise (Luxury category)

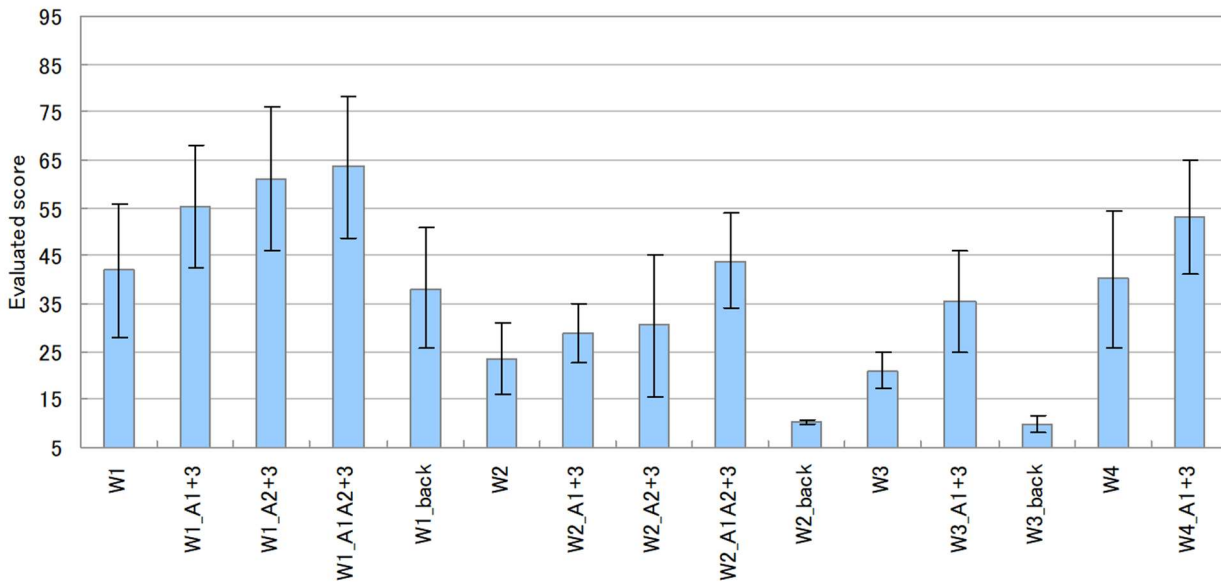


Figure 11: Evaluation of tire pattern noise (Winter category)

4. MULTIPLE REGRESSION MODELS FOR ANNOYANCE OF TIRE PATTERN NOISES

In order to construct models for annoyance for tire patter noise, following variables are defined.

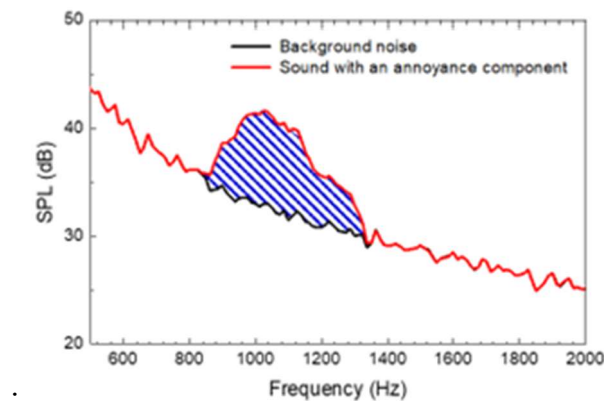


Figure 12: Energy ratio(ER)

Energy ratio ER is define as following formula,

$$ER = 10 \log_{10}(\text{energy within the annoyance component} / \text{energy under the background noise}).$$

Freq_p: frequency at the the top of anyoance component..

P.Loudness: partial loudness(sones) defined as b.andwidth within the annoyance component abobe background noise profile.

For entry category, multiple regression model for annoyance is obtained as,

$$MoEBe_{opt} = 6.94 \cdot ER_p + 0.012 \cdot freq_p + 6.81 \cdot P.Loudness + 1.83 \cdot ER_s - 51.77 \quad (1) \text{for}$$

For Luxury category, multiple regression model for annoyance is obtained as,

$$MoLBe_{opt} = 5.68 \cdot ER_p + 0.008 \cdot freq_p + 4.20 \cdot P.Loudness + 1.68 \cdot ER_s - 26.14 \quad (2)$$

For Winter category, multiple regression model for annoyance is obtained as,

$$MoWBe_{opt} = 6.72 \cdot ER_p + 0.022 \cdot freq_p + 7.35 \cdot P.Loudness + 0.91 \cdot ER_s - 59.45 \quad (3)$$

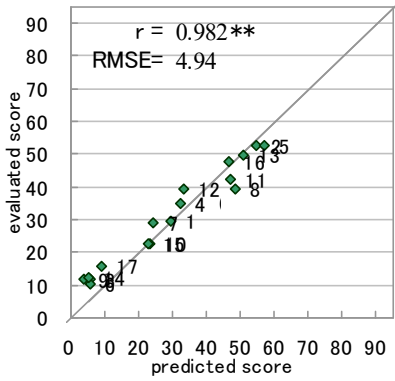


Figure 13: Entry category

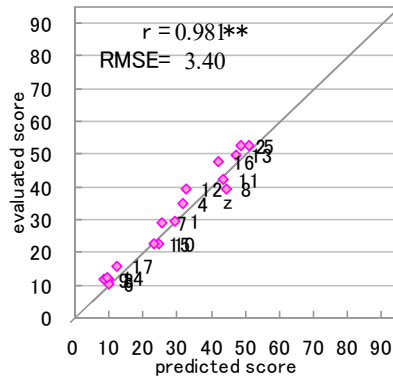


Figure 14: Luxury category

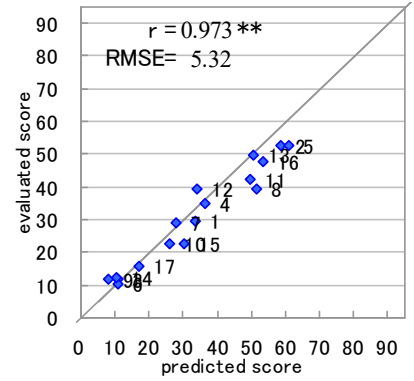


Figure 15: Winter category

As are shown in these three figures, the multiple regression model obtained, namely the formula (1), (2) and (3) represent well with the experimental results. That is to say, we can predict annoyance of tire pattern noise by these three formulas. So, if the magnitude of explanatory variables is defined for better impression, then we can design the sound profile in question. This could be a good measure for producing tires with better impression.

5. CONCLUSIONS

By conducting subjective evaluation of tire pattern noise, we could obtain following conclusions.

1. For the evaluation of tire pattern noise in question, the first process is to obtain background noise profile for the definition of annoyance components.
2. Annoyance component of tire pattern noise is prevailed for the distinct peaky component if other smaller level secondary component exists simultaneously. If this is true for the sound in question, then one peaky component alone should be tested for annoyance. Otherwise, two components should be better to be tested for annoyance.
3. We could have obtained good model for annoyance for various tire categories, then by the utilization of these models, we could design the noise spectrum for better impression.

6. REFERENCE

1. Hashimoto, T. & Hatano, S. *Proceedings of INTER-NOISE 2017*, pp.1-12. Hong Kong, China, August 2017.1).