The metrics of mixed traffic noise: Results of simulated environment experiments

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INTRODUCTION

Some types of noise, including traffic noise, railway noise, and aircraft noise have previously been evaluated individually. However, it is also necessary to consider the combined noise resulting from these sources because residents in urban areas are often exposed to these types of noises simultaneously. In spite of the studies that have considered combined noise, in which different evaluation models have been proposed (Ollerhead 1978; Powell 1979; Flindell 1983; Vos 1992; Kaku 1999), there is little agreement about which model is the most effective (Gjestland 1997). In addition, there have only been a few studies carried out specifically in Japan that have considered combined noise. It is therefore important to consider whether the results obtained from studies carried out elsewhere (including in western countries) are applicable to Japan, given its different culture and the differences in the structure of its cities and houses. This is done by reinvestigating the effects of combined noise, this time in Japan, and collecting additional information related to the study.

The aim of this study is to identify the most effective evaluation model for combined noise. For this purpose, we conducted experiments in the laboratory and social surveys relating to the combined noise of conventional railway and road traffic noise carried out from 2004 to 2006. In this paper, we focus on the results of experiments carried out during this three-year period.

OUTLINE OF THE EXPERIMENTS

Four experiments (one in 2004, two in 2005 and one in 2006) were carried out. These are referred to as Experiment I to Experiment IV in this paper.

Experimental Procedures

The experiments were carried out in a simulated living room located at Yokohama National University (Figure 1). The subjects were asked to evaluate combined noises simulating noises coming from outside a window. Figure 2 shows the flow of the experiment. The subjects were exposed to 5 minutes of stimuli, and were instructed to evaluate the noise after the five minute period had elapsed. In the middle of the experiment, the subjects rested for 10-15 minutes.

The Simulated Living Room and the Anteroom

Figure 1 shows the layout of the simulated living room and the anteroom. The stimuli (combined noises) were produced by speakers in the anteroom. The two rooms were connected by a French window and the curtain on the window was closed. One of the experimenters stayed in the living room and gave instructions to the subjects about the experiment.

Subjects

All of the subjects were students from Yokohama National University, and two subjects participated in each experiment. Table 1 shows the number of subjects. The subjects were confirmed as having normal auditory capacity based on a hearing test. During the experiment, the subjects were asked to read a book in Experiments I and II and to watch a DVD in Experiments III and IV to help identify the effect of differences in activities when the noise evaluations are carried out. The subjects selected one DVD from about 20 titles which all had continuous speech. The subjects were asked to adjust the volume of the DVD playback to the same level at which they would tend to watch at home. During the experiment, the subjects were not allowed to change the volume, to make any significant noises, to speak nor to take a nap.

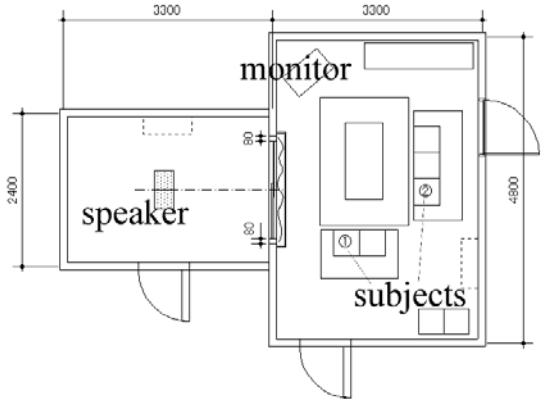

Figure 1: The simulated living room and the anteroom

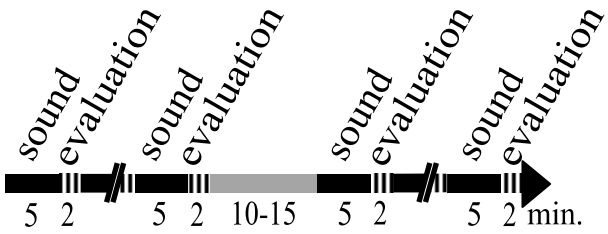

Figure 2: The flow of the experiment

Table 1: The number of subjects and the activity carried out by the subject in each of the experiments

	I	II	III	IV
The number of subjects	40	24	36	24
The activity	Reading a book	Reading a book	Watching a DVD	Watching a DVD

Stimuli

Figures 3-5 show the fluctuation in the stimuli (noises) and Tables 2 and 3 show the outline of the stimuli. The road traffic noise stimuli and conventional railway noise stimuli were edited from a recorded sound source and a DVD sound source. These sounds, adjusted to three levels of volume were mixed, and single sounds (single noise) and mixed sounds (combined noise) were used as the stimuli (Tables II and III). In Experiment IV, the number of trains passing by was 6 and the fluctuation in road traffic noise was smaller than those in Experiments I-III. This was to confirm the effects of the fluctuation of sounds on the evaluation of the noises. However, a detailed discussion about the effect of the fluctuation is beyond the scope of this paper. The stimuli were played back randomly, and half of the subjects were exposed to the stimuli in inverse order to help minimize any possible effects of order. In addition, during Experiments II- IV, about 30 dB of ambient noise was played back continuously because it was found to be extremely quiet inside the living room (less than 20 dB).

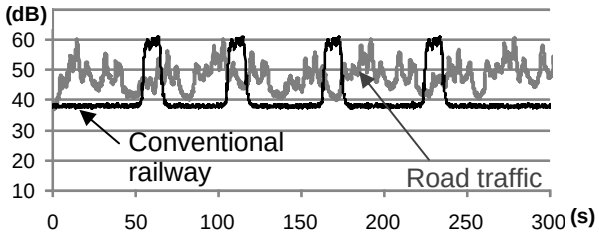

Figure 3: The fluctuation of the stimuli during Experiment I ($L_{Aeq,5min.}$=50dB)

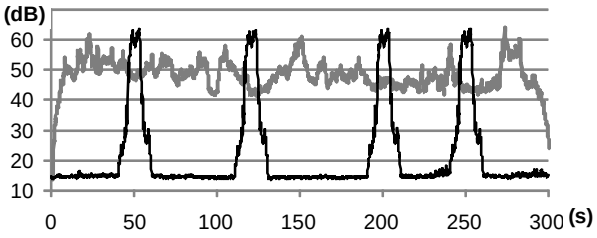

Figure 4: The fluctuation of the stimuli during Experiments II and III ($L_{Aeq,5min.}$=50dB)

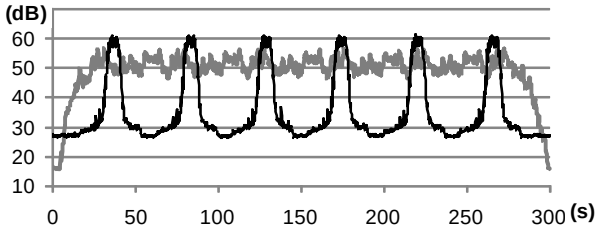

Figure 5: The fluctuation of the stimuli during Experiment IV ($L_{Aeq,5min.}$=50dB)

Table 2: Outline and names of the stimuli druing Experiments I- III

	$L_{Aeq/CR}$ =0dB	$L_{Aeq/CR}$ =40dB	$L_{Aeq/CR}$ =50dB	$L_{Aeq/CR}$ =60dB
$L_{Aeq/RT}$ = 0dB	-	CR40	CR50	CR60
$L_{Aeq/RT}$ =40dB	RT40	RT40/CR40	RT40/CR50	RT40/CR60
$L_{Aeq/RT}$ =50dB	RT50	RT50/CR40	RT50/CR50	RT50/CR60
$L_{Aeq/RT}$ =60dB	RT60	RT60/CR40 *	RT60/CR50	RT60/CR60

$L_{Aeq/RT}$: equivalent noise level of road traffic, $L_{Aeq/CR}$: equivalent noise level of conventional railway
* RT60/CR40 was omitted from Experiment I because the conventional noise was not heard.

Table 3: Outline and names of the stimuli during Experiment IV

	$L_{Aeq/CR}$ =45dB	$L_{Aeq/CR}$ =50dB	$L_{Aeq/CR}$ =55dB
$L_{Aeq/RT}$ =45dB	RT45/CR45	RT45/CR50	RT45/CR55
$L_{Aeq/RT}$ =50dB	RT50/CR45	RT50/CR50	RT50/CR55
$L_{Aeq/RT}$ =55dB	RT55/CR45	RT55/CR50	RT55/CR55

Evaluation Method

The evaluation sheets (Figure 6) were delivered to the subjects after exposure to each stimulus. The subjects evaluated the noise environment for three categories: the total sound environment, road traffic noise alone and conventional railway noise alone. The terms “automobile sounds” and “train sounds” were used to express “road traffic noise” and “conventional railway noise” to avoid excessive specific concerns of noise from the subjects. During Experiment I, the above three categories were evaluated based on “loudness”, “noisiness” and “annoyance”. However, some of the subjects reported that they could not make any distinction between “noisiness” and “annoyance”. As a result, the three evaluation categories were assessed based on “loudness” and “noisiness or annoyance”, and “interference with reading a book” during Experiment II. For Experiments III and IV, “interference with watching a DVD” was used instead of “interference with reading a book”. The range of possible evaluation scores was 0 -10.

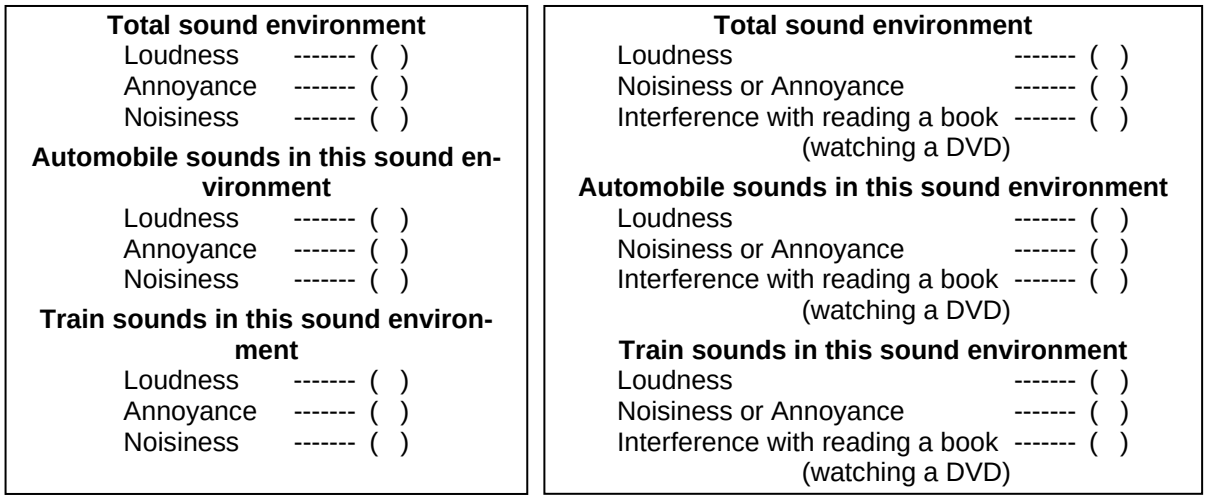

Figure 6: Examples of the evaluation sheet

RESULTS AND DISCUSSION

The results show that there were no significant differences in the mean evaluation scores among “loudness”, “noisiness”, “annoyance” and “interference” in any of the experiments. Therefore, we will focus our discussion on the evaluation of “annoyance” in Experiment I and “noisiness or annoyance” in Experiments II- IV. For the sake of simplicity, when discussing a particular noise, the other noises will be referred to as “background noise”. The resulting values were tested for significant differences at the 5 % level ($P<0.05$) after this.

Total L_{Aeq} and the Evaluation of the Total Sound Environment

Figure 7 shows the relationship between the total L_{Aeq} and the average of the evaluation to the total sound environment in Experiment I as an example. Figure 8 shows the result in Experiment III. Throughout all of the experiments, the evaluation score showed positive correlations with the total L_{Aeq}. However, there were sometimes significant differences found among the evaluation to the same or approximate L_{Aeq}. Throughout all of the experiments, the combined noises with prominent railway noises tended to be found to be less annoying than those with prominent road traffic noises. From this result, it is reasonable to suppose that combined noises can hardly be evaluated based solely on L_{Aeq}. It is thought that the reason for this can be explained by (see also Figure 9):

a. Differences in the dose-response relationships between different traffic noises (Dose-response relationships can be different between each noise type).
b. Interactions between different traffic noises (One noise can have an effect on the evaluation of the other noise).
c. Relationship between the evaluation of the total sound environment and that of each noise (The effect of the evaluation of each noise to the total sound environment evaluation can be different between each noise type).

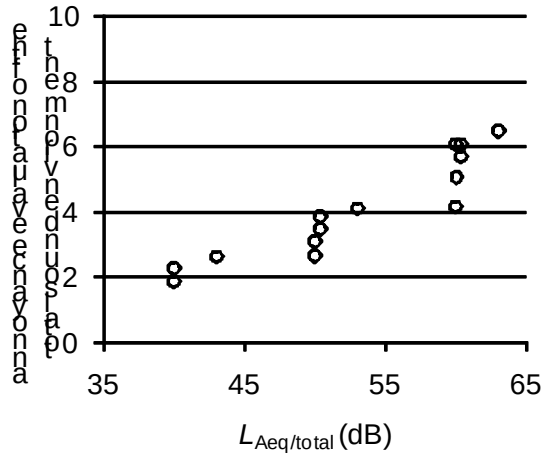

Figure 7: The relationship between the total L_{Aeq} and the evaluation of the total sound environment (Experiment I)

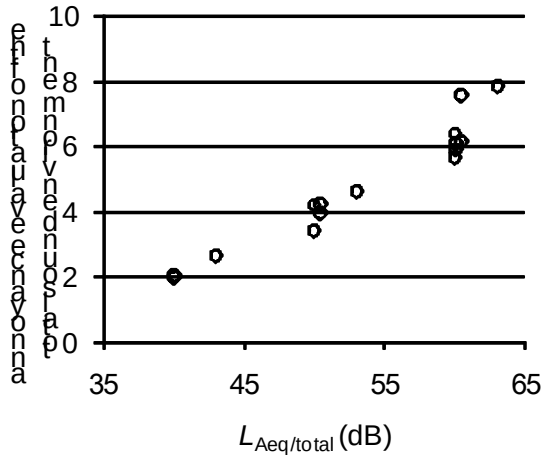

Figure 8: The relationship between the total L_{Aeq} and the evaluation of total sound environment (Experiment III)

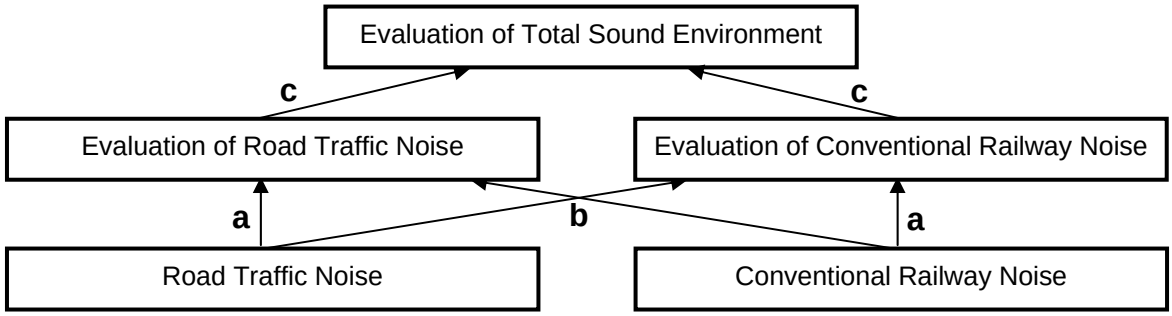

Figure 9: Schematic diagram of the evaluation

Differences in the Dose-Response Relationships between Different Traffic Noises

Figures 10-12 show the relationships between the average annoyance evaluation score of each noise and the L_{Aeq} of each noise in Experiments II-IV when the background noise level was 50 dB.

For Experiment II, for subjects reading books, there were no significant differences found between the road traffic noise and the railway noise, except in the 40 dB range, though conventional railway noise was found to be slightly annoying. For Experiment III, when the stimuli were the same as those of Experiment II but where the subjects were watching DVDs, it was found that the differences between the road traffic noise and the railway noise were significant in the 40 and 50 dB range, and the annoyance response for railway noise was higher than that for road traffic noise. It was thought that the listening disturbance tended to be more severe in the case of railway noise, which has a long duration and high peak value. For Experiment IV, the fluctuations in the noises were different from those in Experiment III, conventional railway noise was found to be much more annoying than road traffic noise. It is supposed that this is due to the road traffic noise which was steadier than that in Experiment III.

From this we can conclude that the relationship between the evaluation and the noise level will be different depending on the task being carried out by the listener. This is because the degree to which a noise is perceived as being a nuisance differs according to the characteristics of the fluctuations in the noise levels.

It is clear that it is not apporpirate to apply the results of laboratory-based studies directly to the evaluation of noise in the real world. This is because the exposure in real-world cases tends to extend over significantly longer periods of time and cause many different interference effects. Therefore, it is also necessary to discuss the results of social surveys to establish an effective combined noise index.

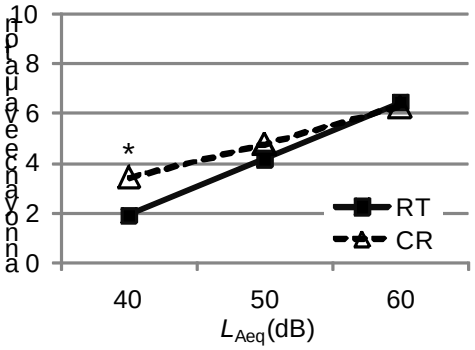

Figure 10: The relationship between the L_{Aeq} of each noise and the evaluation of each noise (Experiment II, background noise: 50 dB)

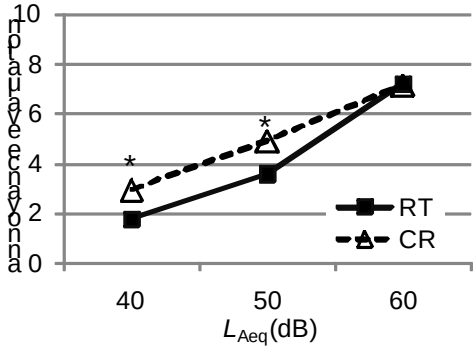

Figure 11: The relationship between the L_{Aeq} of each noise and the evaluation of each noise (Experiment III, background noise: 50 dB)

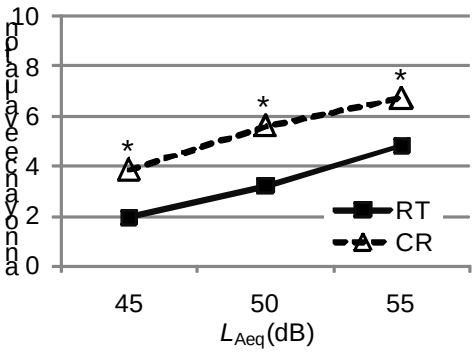

Figure 12: The relationship between the L_{Aeq} of each noise and the evaluation of each noise (Experiment IV, background noise: 50 dB)

Interaction Effects between Different Traffic Noises

We now consider the interaction effects between each type of traffic noise, in other words, the effect of road traffic noise on the evaluation of conventional railway noise and the effect of conventional railway noise on the evaluation of road traffic noise. Figure 13 compares the dose-response relationship of road traffic noise between the levels of conventional railway noise in Experiment I, and Figure 14 compares the dose-response relationship of conventional railway noise between levels of road traffic noise in Experiment III.

At a glance, one noise seems to have little effect on the evaluation of the other noise. None of the experiments showed any obvious evidence of interactions between different traffic noises, though the dose-response relationships were not always exactly the same for the level of background noise, as shown in Figure 14.

From these results, it can be concluded that there are no significant interactions effects. However, it is still possible that interactions occur under some specific conditions.

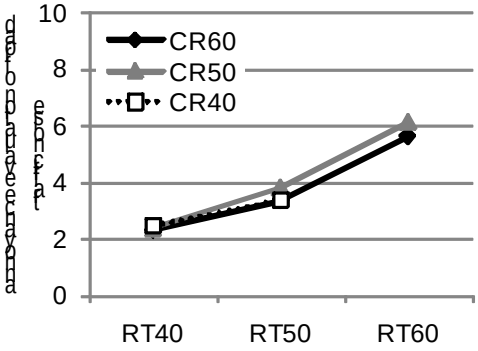

Figure 13: Relationship between $L_{Aeq/RT}$ and the annoyance evaluation of road traffic noise by level groups of conventional railway noise (Experiment I)

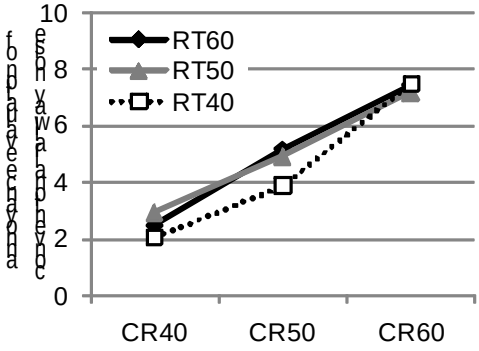

Figure 14: Relationship between $L_{Aeq/CR}$ and the annoyance evaluation of conventional railway noise by level groups of road traffic noise (Experiment III)

Relationship between the Evaluation of the Total Sound Environment and that of Each Noise

Figures 15 and 16 show the evaluation scores for the total sound environment and those of each noise. These figures suggest that the evaluation of the total sound environment approximates that of the more annoying noise. However, the evaluation scores of the total sound environment and those of the more annoying noise were not always the same.

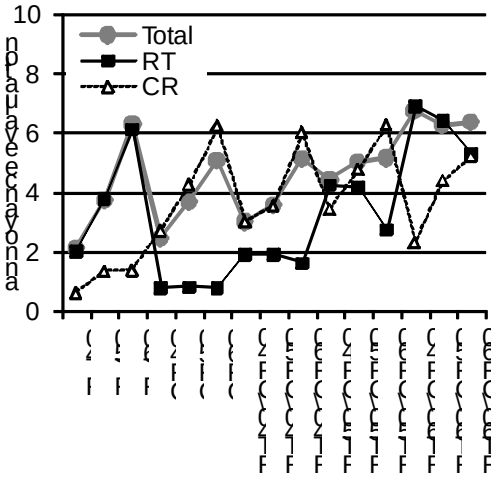

Figure 15: Evaluations of the total sound environment and each noise (Experiment II)

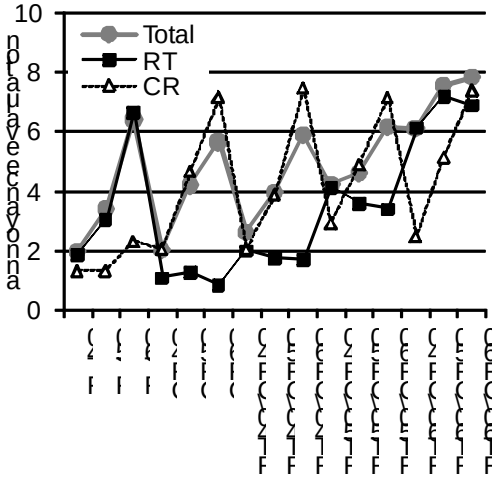

Figure 16: The evaluations of the total sound environment and each noise (Experiment III)

Next, we will discuss the relationship between the evaluation scores of the total noise environment and those of each noise on every experiment. The x-axis in Figure 17 shows the difference in the evaluation scores between each noise, *(road traffic noise evaluation scores) - (conventional railway noise evaluation scores)*. Road traffic noises are more annoying in the right field of the figure and conventional railway noises are more annoying in the left field. The y-axis on this figure shows the difference in the evaluation between the total noise environment and each noise, *(each noise evaluation scores) - (total sound environment evaluation scores)*. In other words, the evaluation scores of each noise are more than those of the total sound environment in the upper field of the figure and the evaluation scores of the total sound environment are more than those of each noise in the lower field. Note that this figure also contains the results of the single noises in Experiments I-III.

From this figure, we can say that the evaluation of road traffic noise approximates that of the total sound environment when road traffic noise is much more annoying than conventional railway noise. On the other hand, when conventional railway noise is much more annoying than road traffic noise, the evaluation score of conventional railway noise is more than that of the total sound environment, though the evaluation of conventional railway noise more closely approximates the total sound environment than that of road traffic noise. When the evaluations of road traffic noise and conventional railway noise are approximate, both evaluations of each noise contribute to that of the total sound environment, and the evaluation score of the total sound environment is slightly more than that of each noise.

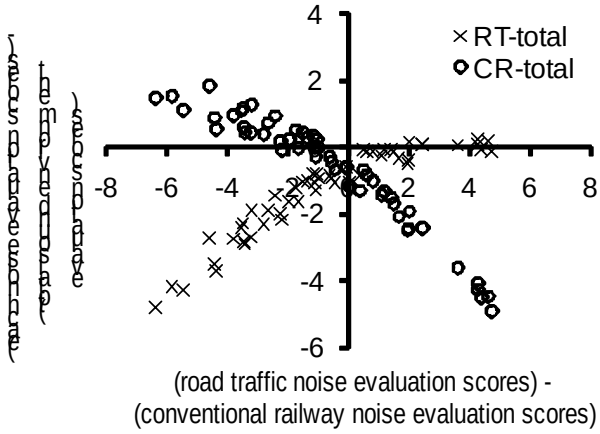

Figure 17: Relationship between the evaluation of the total sound environment and that of each noise

CONCLUSIONS

Combined noises cannot be evaluated based solely on L_{Aeq}. The perceived degree of annoyance of each noise depends on the degree of the nuisance which is affected by the characteristics of the noise fluctuation. Intermittent noise such as railway noise easily causes healing interference. However, when the conventional railway noise is much more annoying than the road traffic noise, the total sound environment is not regarded as being as annoying as conventional railway noise. In this study, we were unable to find any obvious evidence of interactions between road traffic noise and conventional railway noise.

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