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PSYCHOLOGICAL EVALUATION BY VEHICLE NOISE SIMULATOR USING NEW EARPHONE OF EARPLUG TYPE FOR VIRTUAL REALITY

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ABSTRACT
Experiments designed to evaluate the psychological effects (loudness, perceived noisiness and annoyance) of road vehicle noise have basically to be carried out in an anechoic room or a soundproof room. If, however, a simulator based on a virtual reality system capable of audio-visual experiencing for various kinds of noise control elements at a residential site is available; one can select the most suitable noise control technique. This paper discusses whether the simulator with an earplug type earphone proposed can be applied with confidence to the subjective impression of noise control elements for road vehicle noise. As a result, it can be said that the virtual reality system proposed here may be obtained one's feelings of direction, distance and movement with the interaction between audible and visible.

1 - INTRODUCTION
Road traffic is the most widespread source of noise in all countries and the primary reason for annoyance and interference with human activities. As a noise prevention method, if the planner and residents can realistically experience and psychologically evaluate the effect of transmission loss with building materials in the planning stage of houses, it can be said that they can appropriately and economically choose those materials for sound insulation efficiency.

The simulator described here uses (a) a glasstron personal display and some earplug type electroacoustic transducers proposed in the previous paper [1]. They are as follows: (b) the microphones for sound pressure measuring in the external auditory canal, (c) the magnetic earphones adhered to earplugs and (d) the microphones for sound pressure measuring in the small cavity, which is enclosed by the earplug and the eardrum.

In this paper, first, the simulator was discussed experimentally whether it obtains the presence as if there are lots of cars on the road by the virtual binaural recording and reproducing. Second, whether this simulator is effective for an evaluation and enlightenment on noise prevention technique and fosters a better understanding of housing design.

2 - VIRTUAL REALITY SYSTEM FOR VEHICLE NOISE SIMULATOR
This simulator bases on a virtual reality system constructed with the microphones for binaural recording, the earplug type earphones, and the head-mount display (PHILIPS VIV-100). Each character is described in following.

2.1 - Recording microphone
A binaural recording technique involves a problem that is the position of a microphone in the external auditory canal. So, two electret condenser microphones (HOSHIDEN KYUSHU. KUC2423-040540) with 2.6mm in diameter were selected. This size is sufficient to change and fix the position. And, they have flat response until about 9kHz.

2.2 - Earplug type earphones

If a binaural listening is done in a field, it is necessary to reduce background noise. So, a new earplug type earphone [1] was selected. This is composed of an electromagnetic sounder (STAR, MMX01C) adhered to an earplug. If the small microphone adhered to the earplug, it is possible to measure the sound pressure in the external auditory canal. This earphone has flat response from about 200Hz to 8kHz and the mean attenuation of an earplug is about 20dB.

2.3 - Method of level calibration

The reproducing sound pressure level (SPL) has to match in a field. The calibration level was decided as follows: (1) The pure tone (frequency: 500Hz, SPL: 70dB) was used as the signal of calibration. (2) A loudspeaker in a recording field reproduced the pure tone, and it was recorded with the binaural recording method at a distance of 1m from the loudspeaker. (3) The reproducing SPL with the earplug type earphone was adjusted to become 70dB.

3 - PSYCHOLOGICAL EVALUATION FOR FEELINGS OF DISTANCE AND MOVEMENT

From a viewpoint of virtual reality, this simulator was discussed experimentally whether it obtained the feelings of distance and movement by the audio-visual stimuli.

3.1 - Experiment

In the case of single running, various kinds of vehicles were taped by a digital video (SONY DCR-VX1000) at the national route 19 in Nagano City. The distances from the traffic line to the recording points were 2.5m, 5m, 10m, and 20m. The sounds were recorded at each point. The binaural recording microphones were inserted into 1cm from each entrance of the external auditory canals of a subject. It was adjusted to the inserting position of the earplug type earphones.

Subjects evaluated the audio-visual stimuli. First, they judged the distance from the hearing point to the sound image of a passing vehicle. If it was felt in front (back), they answered with a positive (negative) value, and in the case of in head, they answered with 0. Second, they evaluated the naturalness (7: Extremely natural, 6: Very natural, 5: Natural, 4: A little natural, 3: Not too natural, 2: Not natural, 1: Not at all natural) on the movement of passing vehicles. The subjects were ten university students with normal sight and hearing, aged 21 to 26 years.

3.2 - Results

The relation between the distance answered by subjects and the recording point is shown in Fig. 1. It can be found that the perceiving distance is roughly near to the distance from the traffic line to the recording points. The relation between the mean scores of the naturalness on the movement of passing vehicles and the distance of recording points is shown in Fig. 2. It can be found that the mean naturalness on the movement of passing vehicles is "5: natural". As a result, it can be said that this simulator obtains the presence as if there is a running vehicle on the road.

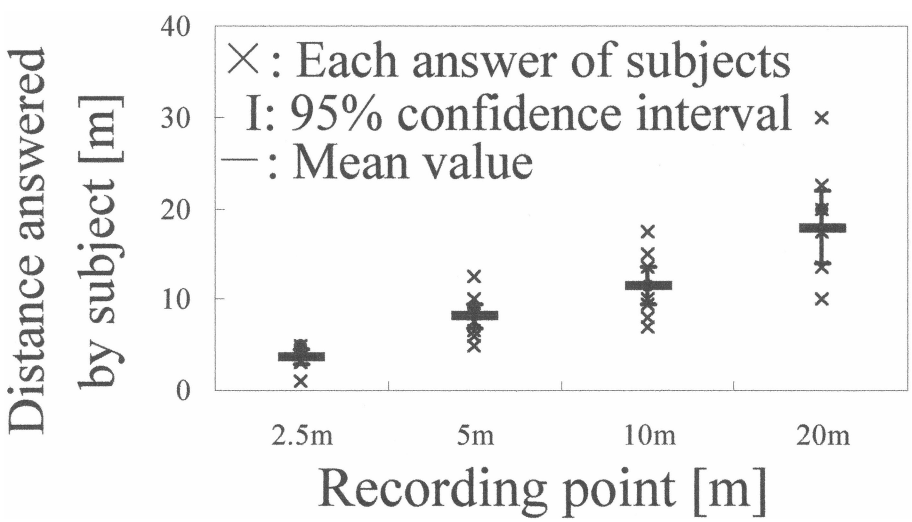

Figure 1: Relation between the distance answered by the subjects and the recording points.

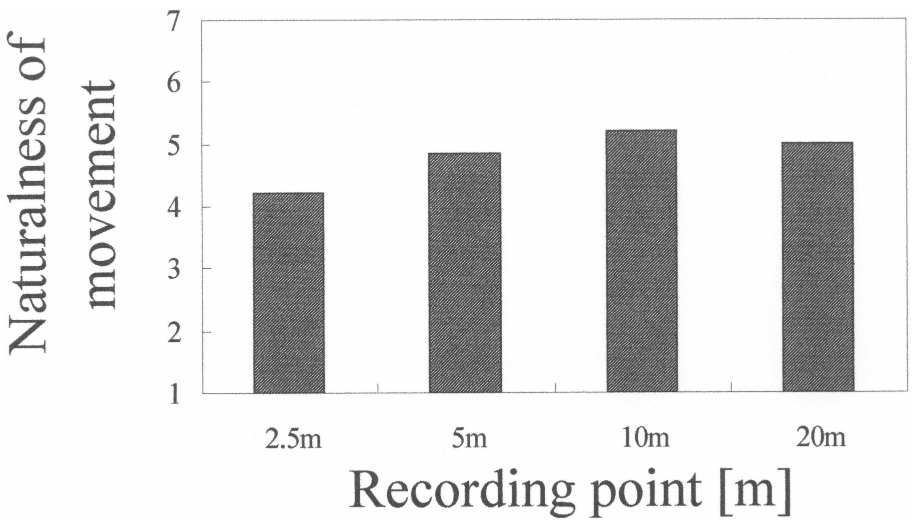

Figure 2: Mean scores of the naturalness on the movement of passing vehicles.

4 - PSYCHOLOGICAL EVALUATION ON TRANSMISSION LOSS

In the case of steady running, this simulator was discussed experimentally whether it obtained the psychological effects (annoyance, effect of transmission loss, and subjective impression of considering all the factors) by the audio-visual stimuli.

4.1 - Experiment

In the case of continuous running, various kinds of vehicles were taped by the same as previous section 3 under the traffic conditions shown in Table 1. The distance from the traffic line to the recording point was 9m. As a general house in Japan, the 4 scenes were simulated under the conditions shown in Table 2.

Traffic [vehicles/5min]	Mean speed of vehicles [km/h]	Mixing rate of heavy vehicles [%]
54	31	28

Table 1: Traffic conditions.

Case No.	Simulated conditions (Hearing point: 9m from the traffic line)	Transmission loss [dB(A)]	$L_{\mathrm{Aeq\ (5min)}}$ [dB]
1	Outdoor image	0	68.3
	No noise control techniques		
2	Outdoor image	10.7	57.6
	A barrier (height: 1.7m) at 5m from the traffic line		
3	Indoor image (house model: 4.2 ×6.0 ×2.3m)	34.5	33.8
	Wall: the composition of wooden, mortar and glass wool		
	A window with single glass (1.15 ×1.6m, thickness: 5mm)		
	A door made of aluminum (0.9 ×2.1m)		
4	Indoor image (house model: 4.2 ×6.0 ×2.3m)	38.2	30.1
	Double window glasses under the condition 3.		

Table 2: Conditions of simulated sounds by FIR digital filter and pictures designed.

The subjects evaluated the stimuli with the three kinds of psychological scales shown in Table 3.

Annoyance	Effect of transmission loss	Subjective impression
		8: Extremely good
3.19: Extremely annoying	7: Extremely effective	7: Very good
2.06: Very annoying	6: Very effective	6: Good
1.15: Annoying	5: Effective	5: A little good
0: A little annoying	4: A little effective	4: A little bad
-0.91: Not too annoying	3: Not too effective	3: Bad
-1.81: Not annoying	2: Not effective	2: Very bad
-3.06: Not at all annoying	1: Not at all effective	1: Extremely bad

Table 3: Psychological scales.

4.2 - Results

The results of regression analysis in each experiment [2], [3] are shown in Table 4. The annoyance score (A), the effect of the transmission loss (E), and the subjective impression (S) are investigated by fitting coefficients in the following linear model through simple regression analysis:

$$A = \alpha + \beta \left(L_{\mathrm{Aeq(\ 5min)}} / 10 \right) \tag{1}$$

$$E = \alpha + \beta \left(TL \right) \tag{2}$$

$$S = \alpha + \beta \left(TL \right) \tag{3}$$

where TL [dB(A)] is the transmission loss, α is the constant, and β is the slope.

	Experiment	Correlation coefficient	Constant α	Slope β	Standard deviation of residual
			Confidence limits (lower limit, upper limit) at level 95%	Confidence limits (Lower limit, Upper limit) at level 95%	
Annoyance (A)	Field	0.792	-4.96 (-5.25, -4.67)	0.95 (0.90, 1.00)	0.98
	Laboratory	0.849	-4.83 (-5.04, -4.62)	0.95 (0.91, 0.98)	0.83
	Anechoic room	0.853	-4.53 (-4.87, -4.19)	0.96 (0.89, 1.02)	0.84
	This simulator	0.871	-5.47 (-6.15, -4.79)	1.09 (0.95, 1.22)	0.988
Effect of transmission loss (E)	Anechoic room	0.629	2.25 (1.85, 2.63)	0.084 (0.071, 0.097)	1.05
	This simulator	0.842	1.68 (1.07, 2.28)	0.12 (0.10, 0.14)*	0.942
Subjective impression (S)	Anechoic room	0.582	2.76 (2.29, 3.25)	0.091 (0.075, 0.107)	1.29
	This simulator	0.835	1.94 (1.22, 2.66)	0.14 (0.11, 0.16)*	1.13

Table 4: Results of regression analysis in each experiment [2], [3] (*: statistical significance at the level of $p<0.05$).

5 - CONCLUSIONS

The vehicle noise simulator based on the virtual reality system using new earplug type earphones was experimentally discussed. From the experimental results of psychological evaluation by this simulator, several conclusions can be given in following:

- The presence, such as feelings of distance and movement, is obtained.
- "Not to annoying" corresponds to 41.8dB of $L_{\mathrm{Aeq\ (5min)}}$.
- "Effective" on the transmission loss corresponds to 28dB(A).

As a conclusion, it can be said that this simulator is useful for the audio-visual experiencing for various kinds of noise control elements at a residential site.

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REFERENCES

1. **S. Matsubara, K. Furihata and T. Yanagisawa**, Electroacoustic Transducers of Earplug Type for Active Noise Control in External Auditory Canal, In *Active 99*, pp. 1257-1266, 1999
2. **S. Okamoto, K. Furihata and T. Yanagisawa**, Vehicle Noise Simulator Based on the Sensory Characteristics of Sight and Hearing, In *Inter-noise 99*, pp. 1777-1782, 1999
3. **K. Furihata and T. Yanagisawa**, Psychological Evaluation on Transmission Loss of Building Materials by Road Vehicle Noise Simulator, In *Inter-noise 2000*, 2000