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Physical measures for auditory source width (ASW): Part 2. Comparison between various physical measures and ASW (Auditory source width)

M. Morimoto*, K. Iida**, K. Sakagami* and A. H. Marshall***

*Environmental Acoustics Laboratory, Faculty of Engineering, Kobe University, Nada, Kobe 657 Japan
**Matsushita Comm. Ind. Co., Ltd., AV & C Research Lab.,.Saedo, Midori,,Yokohama 226 Japan
***Acoustic Research Centre, Department of Architecture, University of Auckland, Auckland, New Zealand

INTRODUCTION

In the previous paper[1], various single number physical measures for ASW are distinguished, considering the physical factors relating the head-related impulse response, $h(t)$. In this paper, which of the physical measures are useful for evaluation of ASW for a wide-band source signal is investigated. Psychological experiments were performed by using the paired comparison test. The sound field used in the experiments was composed of a direct sound and two lateral reflections. Wide-band noises incoherent each other were radiated from a frontal and two lateral loudspeakers.

I. COMPARISON 1: EFFECTS OF FREQUENCY COMPONENTS OF A DIRECT SOUND AND REFLECTIONS ON ASW

Two psychological experiments were performed. In both experiments, the source signal was a pink noise. The azimuth angles of reflections were changed from ±18° to ±90° in steps of 9° (see Fig.1(b) in the previous paper[1]). The SPL of stimulus was 65.0±1.0dBA measured at the left ear of a KEMAR dummy head.

A. Conditions of psychological experiment Ia The frequency components of a direct sound and reflections were identical. The lower cut-off frequency was fixed at 200Hz. The higher cut-off frequencies (Fhc) were 8kHz, 4kHz, 2kHz and 1kHz. The SPL of the reflections relative to a direct sound was fixed at -6dB.

B. Conditions of psychological experiment Ib The frequency components of a direct sound was constant from 200Hz to 8kHz. But the low frequency components of reflections were eliminated. The lower cut-off frequency (Flc) was changed at 200Hz, 400Hz, 800Hz and 1.6kHz. The SPL of the reflections relative to a direct sound was -6dB when Flc was 200Hz. In this experiment, a stimulus composed of the direct sound alone was presented to the subject as one of the test sound fields.

C. Measuring method of physical measures All physical measures listed in the previous paper[1] were measured for stimuli used in the experiments, except for $IACC_{E4}$ in the experiment Ia. In the experiment Ia, $IACC_{E4}$ measured for Fhc=8kHz was used for comparison.

D. Results and discussion Figures 1(a) and (b) show the results of the experiments Ia and Ib, respectively. Figure 1(a) shows that the closer the azimuth angle of lateral reflections gets to 90°, the bigger ASW grows for any Fhc. Furthermore, ASW for any Fhc are almost the same. This means that higher frequency components than 1kHz do not contribute to ASW at all, for the wide-band source signals including low frequency components below 1kHz.

Figure 1(b) shows that ASW is maximum for Flc=200Hz. As Flc increases, the contribution of lateral reflections to ASW decreases. Finally, it is a noticeable finding that ASW for Flc=1.6kHz is equal to that for only a direct sound. In other words, the lateral reflections composed of only frequency components higher than 1.6kHz do not contribute to ASW at all.

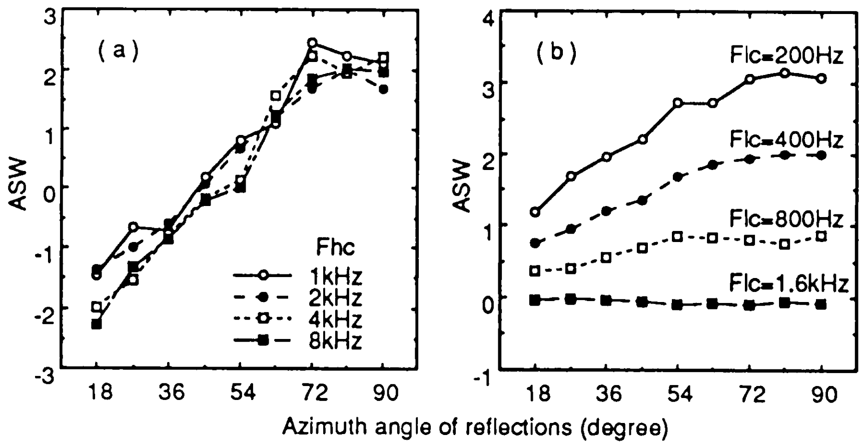

Fig. 1 ASW vs. azimuth angle of reflections; (a) Effects of high frequency components of a source signal on ASW as a function of azimuth angle of reflections. The parameter, Fhc is higher cut-off frequency of a source signal. (b) Effects of low frequency components of reflections on ASW as a function of azimuth angle of reflections. The parameter, Flc is lower cut-off frequency of lateral reflections.

Table 1 shows the adequacy of each of the physical measures listed in Table 1 in the previous paper[1] to evaluate ASW. Yes or No was judged from the following well-known relations between measures and ASW. The measures of the ICC group have a negative correlation with ASW. The measures of the Lf group have a positive correlation with ASW. Furthermore, when Flc is 1.6kHz in the experiment Ib, values of measures of the ICC group and the Lf group should be 1.0 or 0.0, respectively, because ASW for Flc=1.6kHz is equal to that for only a direct sound as shown in Fig. 1(b). The right end column indicates whether ASW for all stimuli used in the experiments Ia and Ib can be consistently evaluated together, or not.

It is found that DICC(1600) and Lf(1600) are adequate for all cases and that Lf and $IACC_{E4}$ are available except one and two cases, respectively. Furthermore, DICC(1600) and Lf(1600) seem to be able to evaluate ASW consistently for all stimuli used in both experiments as shown in Fig. 2. In the figures, dotted lines indicate the 95% confidential interval and dashed-dotted lines indicate the interval outside the 95% confidence interval by 0.68 which corresponds to a just noticeable difference. Lf(1600) has a little higher correlation with ASW than DICC(1600).

Table 1 Adequacy of various physical measures to evaluate ASW

Frequency components of a direct sound and lateral reflections (Hz)									All together
Direct sound		200-1k	200-2k	200-4k	200-8k	200-8k	200-8k	200-8k	
Lateral reflections		200-1k	200-2k	200-4k	200-8k	400-8k	800-8k	1.6k-8k	
Physical measure	IACC	Yes	No	No	No	No	No	No	---
	DICC	Yes	Yes	No	No	No	No	No	---
	DICC(1600)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	$IACC_{E4}$	Yes	Yes	Yes	Yes	Yes	No	No	---
	Suppl. A	Yes	No	No	No	No	No	No	---
	Suppl. B	Yes	No	No	No	No	No	No	---
	Lf	Yes	Yes	Yes	Yes	Yes	Yes	No	---
	Lf(1600)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

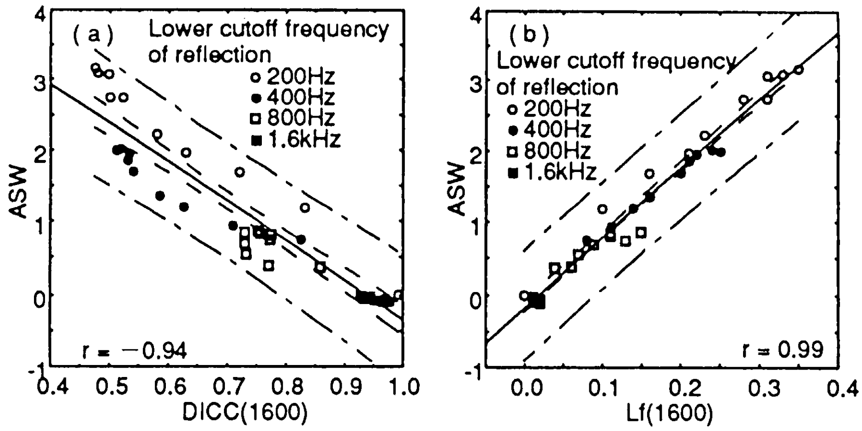

Fig. 2 Comparison between ASW for various lower cut-off frequencies of reflections and (a) DICC(1600) and (b) Lf(1600).

II. COMPARISON 2: ASW FOR A FOUR OCT. BAND NOISE

The results of the experiments Ia and Ib indicate that DICC(1600) and Lf(1600) are most useful for ASW of a wide-band source signal. But $IACC_{E4}$ is also useful except for two cases. The difference between them is whether higher frequency components than 1.6kHz are taken into account or not. The purpose of the psychological experiment II is to address this question directly, using a four oct. band noise composed of four 1/1 oct. band noises with center frequencies of 500Hz, 1kHz, 2kHz and 4kHz, as the source signal.

A. Method of psychological experiment II The frequency components of the direct sound and reflections were identical. The azimuth angles of reflections were fixed at ±90° . $IACC_{E4}$ for all stimuli was constant at 0.7, but the combinations of IACC for each 1/1 oct. band noise were variable as shown in Table 2. The SPL of stimulus was 60.0±0.1dBA measured at the position corresponding to a center of a subject's head.

B. Results and discussion Figure 3 shows ASW on the psychological scale. They are distributed uniformly and widely. The range of distribution is clearly wide comparing with the difference on the psychological scale of 0.68 which corresponds to a just noticeable difference. This means that the ASW varies even though $IACC_{E4}$ is constant.

Figure 4 shows the relation between ASW and DICC(1600) and Lf(1600). DICC(1600) has a highly negative correlation with ASW, while Lf(1600) has a rather lower positive correlation. We conclude from these results that the frequency components of two 1/1 oct. bands with center frequencies of 2kHz and 4kHz should be neglected for evaluating ASW even for the four oct. band noise used in this experiment.

It is necessary to make clear the application of $IACC_{E4}$.

Table 2 Kinds of combination of IACC of 1/1 oct. band of stimulus used in Exp. II

Center frequency	No. of Stimulus								
	1	2	3	4	5	6	7	8	9
500Hz	0.7	0.5	0.9	0.9	0.5	0.9	0.5	0.7	0.7
1kHz	0.7	0.5	0.9	0.7	0.7	0.5	0.9	0.9	0.5
2kHz	0.7	0.9	0.5	0.7	0.7	0.5	0.9	0.5	0.9
4kHz	0.7	0.9	0.5	0.5	0.9	0.9	0.5	0.7	0.7
$IACC_{E4}$	0.7								

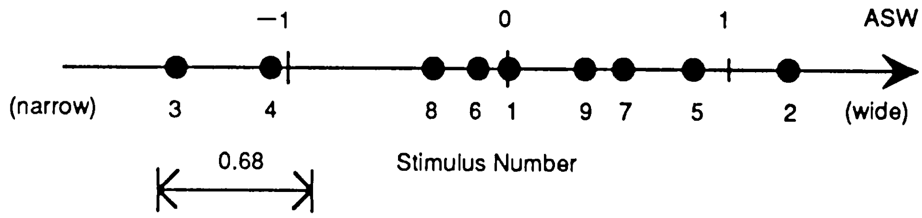

Fig. 3 Psychological scale of ASW for nine kinds of stimuli with the same $IACC_{E4}$. Numbers indicate the kind of combination of IACC for each 1/1 oct. band (see Table 2). The psychological distance of 0.68 corresponds to just noticeable difference.

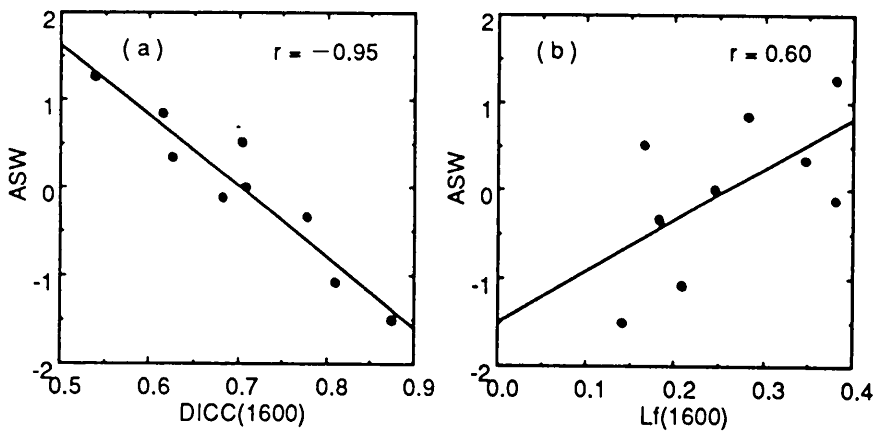

Fig. 4 Comparison between ASW for nine kinds of stimuli with the same $IACC_{E4}$ and (a) DICC(1600) and (b) Lf(1600).

III CONCLUSIONS

The results of three psychological experiments on ASW when the source signal includes frequency components below 1.6kHz show that:

(1) If the frequency components of a direct sound and reflections are identical, the frequency components higher than 1kHz do not contribute to ASW at all. For these conditions, Lf, DICC(1600), Lf(1600) and $IACC_{E4}$ have a good correlation with ASW as a single number physical measure.

(2) If the low frequency components of reflections are eliminated, as Flc (lower cut-off frequency of reflection) increases, the contribution of lateral reflection to ASW decreases. It is a noticeable finding that ASW for Flc=1.6kHz is equal to that for only a direct sound. In other words, the lateral reflections composed of only higher frequency components than 1.6kHz do not contribute to ASW at all. For these conditions, DICC(1600) and Lf(1600) have a good correlation with ASW. Lf and $IACC_{E4}$ have a good correlation with ASW except for Flc=800Hz and Flc=800Hz and 1.6kHz, respectively.

(3) Furthermore, DICC(1600) and Lf(1600) are regarded as being adequate to evaluate ASW consistently for all stimuli used in the experiments Ia and Ib.

The results of the psychological experiment on ASW when the source signal is a four oct. band noise composed of four 1/1 oct. band noises with center frequencies of 500Hz, 1kHz, 2kHz and 4kHz show that:

(4) ASW varies even if $IACC_{E4}$ is constant.

(5) $IACC_{E4}$ has a poor correlation with ASW because it includes the 2kHz and 4kHz frequency components.

REFERENCE

[1]"Physical measures for auditory source width (ASW) : Part 1. Discussion of the competing measures, Degree of interaural cross correlation(ICC) and Lateral fraction(Lf), as a measure of ASW. " M. Morimoto, K. Iida, K. Sakagami and A. H. Marshall, in this proceedings (1994).