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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 (Auditory source width)

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INTRODUCTION

Recently there has been a demand for measurements of ICC as a physical measure for ASW in concert halls. Standardization of these measurements has been also discussed at ISO[1]. The relationship between ICC and Lf has also been studied. This paper gives fundamental consideration to a physical measure for subjective evaluation of a sound field and classifies both ICC and Lf into several kinds of measures based on the measurement methods. Finally, the relative importance of ICC and Lf measures for ASW is discussed in terms of their differences.

I. FUNDAMENTAL CONSIDERATION OF PHYSICAL MEASURES FOR THE SUBJECTIVE EVALUATION OF A SOUND FIELD

In general, physical measures for psychological evaluation can be classified into the following three types based on their usefulness.

<Type A> Measures which consistently represent psychological effect for all source signals and all sound fields.

<Type B> Measures which consistently represent psychological effect for all sound fields but for only some source signals. For other source signals, even if values of the measure are the same, they do not cause the same psychological effect.

<Type C> Measures which consistently represent psychological effect for all source signals but for only some sound field. For other sound fields, even if values of the measure are the same, they do not cause the same psychological effect.

The difference between them is whether the psychological effect to be evaluated depends on the source signal or not. Ideally, to be excellent, a measure must be Type A. But this time such a measure is not known, simply because the physical cues for the psychological phenomenon are not yet clear. Measures for ASW as a single number are not Type A but Type B according to many past experimental results.

II. KINDS OF ICC AND Lf BASED ON MEASURING METHOD

ICC is defined as follows;

$$ICC = |\Phi_{lr}(\tau)|_{max} \qquad (1)$$

where $|\tau| \leq$ maximum interaural time difference. The interaural cross correlation function is generally defined as:

$$\Phi_{lr}(\tau) = \lim_{T \to \infty} \frac{\frac{1}{2T}\int_{-T}^{+T} p_l(t)p_r(t-\tau)dt}{\frac{1}{2T}\sqrt{\int_{-T}^{+T} p_l^2(t)dt \int_{-T}^{+T} p_r^2(t)dt}}$$

where $pl(t)$ and $pr(t)$ are the signals at the left and right ears, respectively and described as follows.
$pl(t)= s(t)*r(t)*hl(t)$
$pr(t)= s(t)*r(t)*hr(t)$.
$s(t)$: source signal, $r(t)$: room impulse response, $h(t)$: head-related impulse response and * indicates convolution.

Lf is defined as follows[3];

$$\mathrm{Lf} = \frac{\int_{5ms}^{80ms} p^2(t)\cos\alpha \, dt}{\int_{0ms}^{80ms} p^2(t)dt} \qquad (2)$$

where $p(t)=r(t)$, and α is the direction of incidence of the arriving sound relative to the axis through the listener's ears.

As shown Eqs (1) and (2), ICC depends on $s(t)$ and $h(t)$. But Lf depends only on $r(t)$. In other words Lf is purely a measure of the sound field in a room or simulated room but ICC includes head characteristics as well. It can be argued that having a primary relationship to the space and surfaces in a room makes Lf more directly useful to a designer than ICC. IACC and several measures based on ICC (ICC group) have been proposed. Though all of them are defined by Eq.(1), they should be distinguished, since they are affected by not only $s(t)$, but also $h(t)$. $h(t)$ can be considered as the acoustical characteristics

Table 1 Kinds of single number derived from ICC and Lf as a measure of ASW

Group	Physical measure*a)	Ear canal simulator	Frequency weighting	Frequency range
Degree of interaural cross correlation	IACC	No	A-weight	All pass
	DICC*1	No	Flat	All pass
	DICC(1600)*1	No	Flat	Low pass (Fc=1.6kHz)
	$IACC_{E4}$	No	Flat	Ave. of four 1/1 oct bands (500, 1k, 2k, 4kHz)
	Supple. A	Yes	Flat	All pass
	Supple. B	Yes	A-weight	All pass
Lateral energy fraction	Lf	---	Flat	All pass
	Lf(1600)	---	Flat	Low pass (Fc=1.6kHz)

*a) IACC(Ando[4]), DICC (Morimoto and Iida[5])*1, DICC(1600) (Morimoto and Iida[5])*1, $IACC_{E4}$(Hidaka, Beranek and Okano[6]), Lf(Barron and Marshall[7]), Lf(1600) (Morimoto, Iida , Sakagami and Marshall (this report)). Supple. A and B are not yet discussed, but the former is a value obtained using the dummy head recommended by ISO (draft)[1].

*1 DICC and DICC(1600) were named as ASWIC and ASWIC(1600), respectively in the authors' paper[5] of a receiving system in ordinary acoustical measurements like RT measurement. The value of ICC depends on how $h(t)$,is treated, even for the same source signal.The way $h(t)$ is treated is the key to the usefulness of the measure. Six measures of the ICC group and two ones of the Lf group are listed in Table 1, considering physical factors relating to $h(t)$.

Supple. A and Supple. B have never been named and discussed. But Supple. A is a single number measured by using a dummy head proposed in the ISO(draft)[1] and Supple. B is the same but including A weighting. Lf(1600) is Lf measured through a low-pass filter(Fc=1600Hz) as is DICC(1600), considering that the low frequency components contribute to ASW [7]. Lf(1600) is a measure which has never been investigated. Though Barron and Marshall[3] infer that low frequency components below around 1.0 kHz are important to ASW, this effect has not yet been compared quantitatively with ASW.

III. RELATION BETWEEN IACC and Lf

Before investigating availability of each measure listed in Table 1, the relation between IACC and Lf is now discussed on the basis of measured values. The measurements were performed using a simple sound field composed of a direct sound and two lateral reflections. 1/1 oct. band noises which were incoherent each other were radiated from a frontal and two lateral loudspeakers. The center frequencies of the 1/1 oct. band noises were 500Hz, 1kHz, 2kHz and 4kHz.

The measurements were performed for the following two cases. In case(a), the direction of lateral reflections was fixed at ±90° and the SPL of the reflections relative to the direct sound was changed. In case (b), the SPL of the reflections relative to the direct sound was fixed at - 6 dB and the directions of lateral reflections were changed from ±18° to ±90° in steps of 9°. Figure 1 shows the loudspeaker arrangements in both cases. But here, DICC was measured instead of IACC. Since the source signals were 1/1 oct. band noises from 500Hz to 4kHz, the effect of A-weighting on measured values was considered to be negligible and DICC can be considered to be equivalent to IACC.

Figure 2 shows the results of measurements. In case (a), DICC has a highly negative correlation with Lf for any frequency. In case (b), DICC has a negative correlation with Lf for 500Hz, but DICC has a complex relationship with Lf for the other frequencies. For any frequency, the closer lateral reflections get to 90°, the larger Lf becomes. But DICC has a peak at 81° for 1kHz and it has a complicated behavior for 2kHz and 4kHz.

The difference between IACC and Lf is that the former depends on $s(t)$ and $h(t)$, but the latter does not, as shown Eqs (1) and (2), and this appears clearly if the direction of reflection changes. The relation between them is complicated if the center frequency of a source signal exceeds about 1kHz. Therefore, when several sound fields are evaluated, IACC and Lf do not always show the same tendency depending on the spatial configuration of the sound field. It is thus dangerous to dismiss one or other of these measures on the basis of limited experimental results as some authors have been inclined to do.

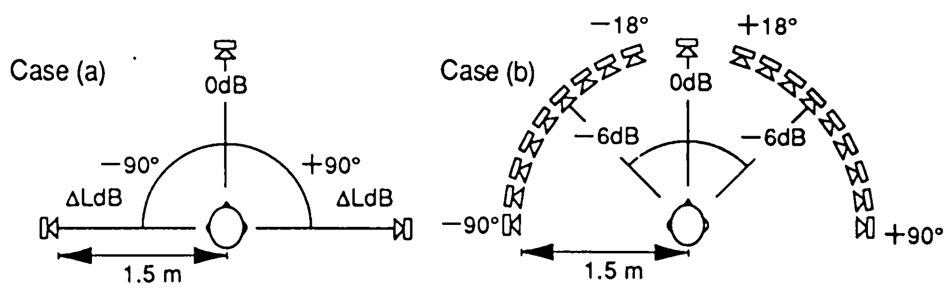

Fig. 1 Loudspeaker arrangements for measurements of DICC and Lf.

IV. CONCLUDING REMARKS

Which of the measures is most useful for evaluation of ASW depends on its dependence on the direction of the lateral reflection. In particular, it is most important to note that the dependence of measures belonging to the ICC group is affected by the frequency components of the source signal and by the treatment of the head-related impulse response, $h(t)$ which is regarded as an acoustical characteristics of the receiving system.

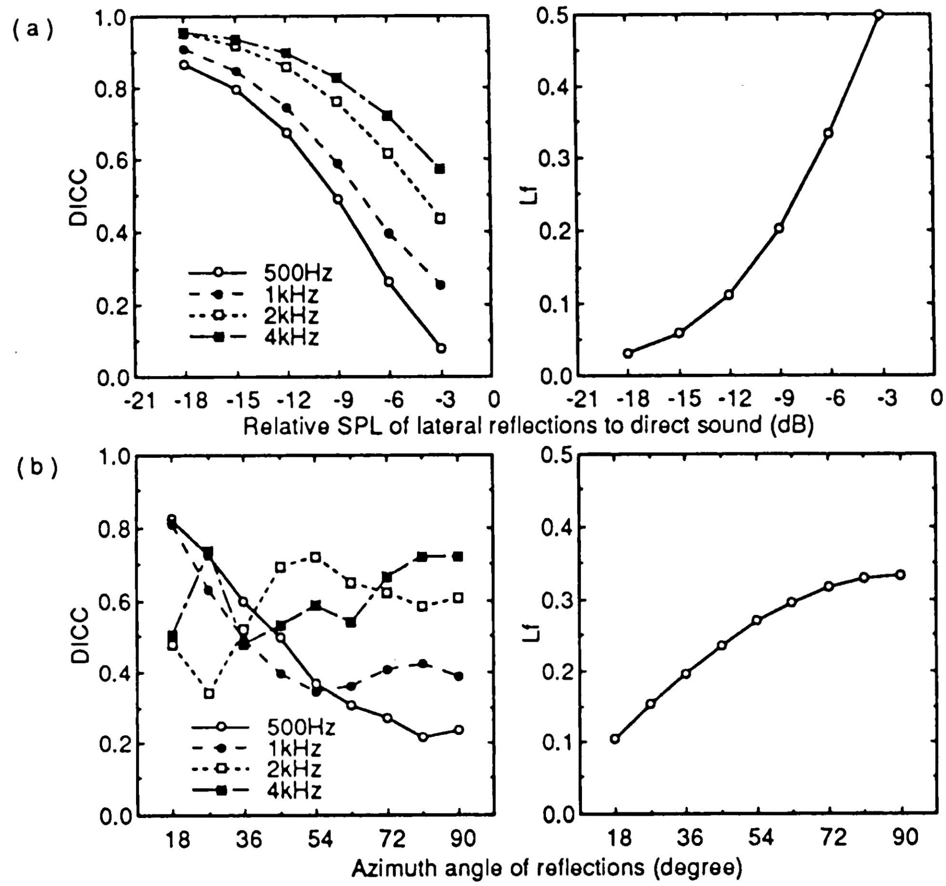

Fig. 2 Comparison between DICC and Lf. In case (a), the azimuth angle of reflections was fixed at ±90° and their SPL relative to the direct sound was changed. In case (b), the azimuth angle of reflections was changed and their SPL relative to the direct sound was fixed at -6dB.

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