



EFFECTS OF REVERBERATION TIME AND SOUND SOURCE CHARACTERISTIC TO AUDITORY LOCALIZATION IN AN INDOOR SOUND FIELD

Chiung Yao Chen

School of Architecture and Urban Design, Chaoyang University of Technology Wufeng, Taichung, Taiwan <u>chychen@cyut.edu.tw</u>

Abstract

According to the reports by Morimoto (1989)¹ regarding the influences of the sound localization of spatial perception in a hall, the reverberation energy (RT60 = 0.3, 0.9 sec) may be treated as the first reflection energy (delay time = 80, 160ms). However, the selection of music is exclusively limited to using Wolfgang Amadeus Mozart's Symphony No. 41, Movement IV as a music source. We intended to prove that the sensitivities on sound localization of spatial impression will vary depending on the structural characteristics of music. Therefore, the other three sound sources: Motif A (Royal Pavane by Gibbon, $\tau e = 127$ ms), Motif B (Sinfonietta, Opus 48; III movement; Allegro con brio by Arnold, $\tau e = 35$ ms) and Speech (female, $\tau e = 23$ ms) were adopted. According to the sound field design theory described by Ando $(1985)^2$, the determining factor of an ideal reverberation time length lies in the effective delay of autocorrelation function (*te*) of sound sources. The reverberation time of our experiments was set at: short (0.3 sec.), medium (0.9 sec.) and long (2.0 sec.) respectively. The judgments of the apparent sound localization were responded from 12 participants by way of scaling using a normal distribution between two horizontal stimuli angles. The result shows that Motif A obtained the highest accuracy level while speech hit the lowest (p < 0.01). The primary cause was the different τe proposed by Ando (1985)²; namely, the significant difference sensation of reverberate image between motifs will have an influence on human's auditory spatial perception of sound source. Furthermore, with respect to the reverberation time, no difference in spatial perception influence was obtained here.

1. INTRODUCTION

The experiences of visual interaction with the direction of sound source at the stage of opera or a classical orchestra have sometimes failed to catch the scene of the performance with respect to the distance or wide stage. But, it is important and cheering for the audiences to trace and immediately respond to the present player on the stage as if the source directional sensitivity in a diffusing sound field were accurately installed. In this paper, we tried to compare the source directional sensitivity of spaciousness as caused by early reflections on a horizontal angle. The simulated sound fields were created by an opinion that reverberation can create the same

degree of spaciousness as early reflections within a shorten delay time after the direct sound, if their ratios of lateral to frontal sound energy are the same. Morimoto (1989)¹ reported that of early reflections at the PSE of spaciousness shows that they are comparable, but early reflections seem to be generally slightly lower than reverberation levels. The calculated correlation coefficient between them is 0.89; that is the reverberation level correlated well with the early reflections level at the PSE. The regression equation is: (early reflection level) = (reverberation level) - 1.27(dB). This equation means that both levels are fairly proportional to each other and that the averaged difference is 1.27dB. On the other hand, Inoue et al. $(1987)^3$ reported recently that the preference of sound impression did not increase with spaciousness throughout, but may have a maximum value at certain spaciousness, that is, the audience does not prefer excessive spaciousness. We believe this to be correct especially for solo performers because spaciousness is inversely proportional to auditory distinction of an auditory event, especially source direction. Since it is well known that spaciousness is strongly related to good acoustics of concert halls, it is an important problem to estimate spaciousness perceived in concert halls. It is assumed that apparent difference of source directional sensitivity of auditory spaciousness is caused by music source, not by reverberation time.

Let us consider the reason for the proposed time gap of early reflection after direct sound. We could not and any definitive proof except the experimental results of Barron; namely that sound adds with early reflections give the same spaciousness (he used the term "spatial impression") with and without a reverberant add present later than 80 ms. Yet, it is not easy for us to adopt 80 ms as the time limit, because it does not become clear in his experiment whether an increase of energy by additional reverberation could exceed the differential limen (DL) of spaciousness, supposing that the same energy were added within 80ms. On the other hand, Bilsen (1983)⁴ reported from his experimental results that the perceived spaciousness could be increased by adding reverberations. As a matter of fact, when we casually tried to listen to sound adds with and without reverberation ourselves; we could actually perceive an increase in spaciousness when reverberation was added.

Barron and Marshall (1981)⁵ have described in their article that the value for lateral energy fraction, Lf, as calculated for a series of theoretical reflection sequences for two rectangular halls gave virtually identical values no matter whether 80 ms or 100 ms was used as the limiting delay value for the early lateral reflections. Yet, if all of halls had such a shape as in the examples cited by Barron and Marshall, there would be no cause of distress for acousticians. But, in reality, architectural designers are apt to design concert halls with shapes that puzzle the acousticians. Furthermore, it has recently become feasible to add reverberation by using electro- acoustical equipment. Ando $(1985)^2$ reported the most preferred delay time of early reflections after the direct sound differs greatly between the two motifs. When the amplitude $A_1 = 1$, the most preferred delay are around 130 ms and 35 ms for Motifs A and B respectively. It is found that this corresponds to effective durations (τe) of the autocorrelation function (ACF) of source music of 127 ms (motif A) and 35 ms (motif B). In order to represent the geometrical size of a similar room, the delay time of subsequence reflection is introduced as $\Delta t_2 = \Delta t_1 + 0.8$ Δt_1 . In order to satisfy the preferred situation in auditory spaciousness, we arranged the delay time gap of early reflection and subsequence reflections after the direct sound to be obeyed the suggestions proposed by Ando $(1985)^2$.

In this study, the term "auditory localization" was defined as the early reflection of an auditory event perceived temporally and spatially to be fused with the auditory event of a direct sound and subsequence reverberation in an enclosure like a concert hall.

2. EXPEREMENTAL CONDITIONS

A method of adjustment using LED unit by the subject was employed in this experiment. To



Figure 1. Measuring set-up.

the subject five azimuth angles of early reflections were presented for comparison, and he could switch the source direction carefully with a LED unit equipment (Figure 1) during the passage of the musical motif, apparently perceived. In all experiments, the subjects were asked to judge the horizontal source direction in auditory spaciousness.

2.1 Apparatus

Figure 1 shows the experimental arrangement. Seven loudspeakers were arranged in the semianechoic chamber of the acoustical studio at the Chaoyang University of Technology. The first loudspeaker was in front of the subject at a distance of 1.5m. This 1 oudspeaker was used to radiate the direct sound. One further loudspeaker stood at azimuths of +108°, also at a 1.5m distance, used to radiate reverberation. The direct sound was played by digital system controlled on desktop PC derived from a DAT tape recorder (TEAC R-9) and delivered directly to the front loudspeaker. The single early reflection and the reverberant signal with time delay of preferred gap proposed by Ando $(1985)^2$ mentioned above and the reverberation time T60s were created by a digital reverberator (YAMAHA Pro R3). They were directly delivered to the right loudspeaker (+108°) and to the left loudspeaker (-18°, -36°, -54°, -72°, -90°), which delay gap were also created by the digital system on desktop PC. We could simulate five kinds of sound fields, which all consisted of the direct sound plus reverberation and plus early reflection with arbitrary five azimuth angles. The levels of the early reflections and the reverberant signals relative to the direct sound were measured by a noise meter (ONO SOKKEI LA-5110) placed above the head of the subject. For the level measurements, pink noise was used as source signal. In our experimental arrangement, the digital system was operated by the experimenter and the switch of LED unit was operated by the subject and the judgement results were shown to a monitor outside the chamber. The LED unit could display each 2.5° azimuth angle; the results of experiments were scaled using normal distribution function as below, the score was 100 as the answer is absolutely right to the present angle, and 0 showed answer was different angle to the present one.

$$SCORE = \frac{1}{\sqrt{2\pi}} e^{-\frac{(angle)^2}{2}}$$
(1)



Figure 2. Signal configuration.

Figure 2 shows the level and time delay structure of each signal was constantly arranged for three motifs respectively for all situations in our experiments. All data of three motifs are shown in Table 1.

2.2 Musical Motif

The motifs used for the experiments were all initial 5s section of Symphony music; they are: (A). Royal Pavane composed by Orlando Gibbons, (B). Sinfonitetta, Opus 48, IV movement composed by Malcolm Arnold, and (S). Speech "In language infuse the T many words become read the small set later." Poem read by a female, recorded by Burd (1969)⁶ in the anechoic chamber of BBC.

2.3Subject

Twelve experienced males, ages 25 ± 2 years, with normal hearing sensitivity served as subjects.

Motif	Δt_1	Δt_2	e of ACF of sound source	tempo
А	127 ms	229 ms	127 ms	slowly
В	35 ms	63 ms	35 ms	quickly
S	23 ms	41 ms	23 ms	quickly

Table 1. Experimental arrangement for three motifs.

3. METHODOLOGY

At first, sound field consisted of the direct sound plus reverberation and plus early reflection with arbitrary five azimuth angle, shown in Figure 1 was presented to 12 subjects. The subject was asked to adjust the level of source directional sensitivity to the maximum possible azimuth angle under the auditory spaciousness they perceived.

Next the subject was confronted with five kinds of sound fields for judgement. One of them was the sound field composed of three motifs and three reverberation time at the level or delay gap previously adjusted. The subject was asked to point out the sound direction with regard to spaciousness by controlling the level of the early reflections as shown in Figure 2. The subject could switch at will between five azimuth angles using LED unit equipment.

After each angle adjustment, the experimenter recorded the results from the LED unit to calculate the score with Equation (1). Reverberation times T60 of 0.3, 0.9 and 2.0s, and the source signal Motif A, B and S were used for the experimental sound field. The early reflection was radiated at different azimuth angle of -18°, -36°, -54°, -72°, and -90° throughout the three motifs. Each measurement was repeated three times, yielding a total of 135 experimental results altogether for each subject.



Figure 3. Score of auditory source directional sensitivity were obtained by changing the coming azimuth angle of early reflection for three Motifs and different reverberation time.

4. RESULTS AND DISCUSSION

All data of twelve subjects are shown together in Figure 3. A two-way (Motif * T60) factor analysis of variance indicates significant individual difference between three Motifs (p < 0.01, except -90°, p < 0.05) for all experimental conditions. But the two-way factor analysis of variance indicates no significant difference between three conditions of T60. And there is no interference between two factors for all experimental conditions.

The abscissa is the reverberation time (T60) of the reverberant signals adjusted to be 0.3, 0.9 and 2.0s in the sound field of a direct sound plus reverberation and the early reflection. The ordinate is the score of source directional sensitivity obtained by changing azimuth angle of early reflection, perceived coming direction under a situation of the total stationary level of two signals at the PSE of spaciousness in the sound fields after direct sound reported by Morimoto (1989)¹. This condition indicates all of levels of reverberation and early reflections at echo threshold at the PSE are the measured threshold of the level of for spaciousness. This means that all test sound fields could make the subjects to perceive spaciousness after the direct sound field as same as the auditory sensation in an indoor sound field.

Furthermore, the directional sensitivity of early reflection with the preferred initial time delay for three Motifs are obviously higher (p < 0.001) as τe of ACF of the source signal is longer itself.

On the other hand, in addition to the directional sensitivity of spatial impression, Ando $(1985)^2$ suggested inter- aural cross- correlation coefficient (IACC) controls the preference of spaciousness for the concert hall. Let's look into the measured values of IACC for five situations changed by the azimuth angle of early reflection. The results of measurements of IACC measured using Gauss noise are 0.45 to -18°, 0.36 to -36°, 0.33 to -54°, 0.35 to -72°, and 0.40 to -90°. They are not obviously in connection with the results of source localization in this study.

Consequently, it can be considered that if both levels of early reflection and reverberation are fairly proportional to each other and that the averaged difference is 1.27dB, the degrees of source directional sensitivity caused by early reflection are nothing to do with the subsequence reverberation.

5. CONCLUSIONS

The following experimental hypotheses are supported by the results of the preceding psychoacoustical experiments regarding the contribution of τe of ACF of the source signal, subjective preference on auditory spaciousness.

(1) Reverberation cannot influence the degree of source directional sensitivity as early reflections after the direct sound, if their ratios of lateral to frontal sound energy are the same. (2) The source directional sensitivity caused by different source signal is suppressed by τe of ACF of itself even if the sound field includes both early reflections and reverberation and with their preferred initial time gap after direct sound signal.

(3) The source directional sensitivity are wicker as the coming direction of early reflection sounds located at the azimuth angle from 36° to 54° as the early reflection functions as lateral energy fraction.

These facts point out that temporal characteristics of source signal should be taken into account when estimating and measuring physical measures, like the lateral energy fraction and the inter- aural cross- correlation coefficient, to estimate source localization sensitivity.

REFERENCES

- [1] M. Morimoto and C. Posselt, Contribution of reverberation to auditory spaciousness in concert halls, J. Acoust. Soc. Jpn.(E)10, 2, pp. 87-92, 1989.
- [2] Y. Ando, "Calculation of subjective preference at each seat in a concert hall," J. Acoust. Soc. Am., 74, pp. 873-887, 1983.
- [3] T. Inoue, T. Nishi, T. Wakuri, Y. Shimizu, and F. Kawakami, "Relation between the lateral component of early reflections sound energy and the spatial impression," Proc. Spring Meet Acoust. Soc. Jpn., pp. 557-558, 1987(in Japanese).
- [4] F. Bilsen and F. Brinkman, "On the perception of spaciousness with artificial head, "11th Int. Cong. Acoust., pp. 135-138 (Paris), 1983.
- [5] M. Barron and A. H. Marshall, "Spatial impression due to early lateral resection in concert hall: The deviation of a physical measure," J. Sound Vib-77, pp. 211- 232, 1981.