On the Temporal Design of Environments

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(Received 13 February 2003; accepted 30 September 2003)

An initial approach is made here of temporal design in architecture and in the environment for man. As an introduction, effects of the aircraft noise on developments of the body of unborn babies are mentioned [Ando and Hattori, British Journal of Obstetrics and Gynaecology, 84, 115-118, 1977]. And effects on development of the cerebral hemispheres of children (mind, and in tern, personality) [Ando and Hattori, Journal of the Acoustical Society of America, 62, 199-204, 1977; Ando, Journal of Sound and Vibration, 127, 411-417, 1988; and 241, 129-140, 2001] are described. These were investigated around the Osaka International Airport. From these results, it is noticed what could be thought of as three stages of human time as below. Unlikely time is money, but time is life:

(1) time of the body;
(2) time of the mind; and
(3) time of personality.

The third life is the source of creation and the most unique to man. All healthy creations that may contribute to human life for a long time have been based on the unique and healthy personality of the individual. It is highly recommended, therefore, that the environment be designed for every stage of time, which is deeply related to each individual. A well-designed environment would be a meeting place for art and science, and in turn may help to discover the individual personality as the minimum unit of society.

An attempt is made here for design theory of sound fields in a concert hall based on the model of auditory-brain system together with subjective preference as a primitive response [Ando, Architectural Acoustics, AIP Press/Springer-Verlag, New York, 1998]. A seat selection system to maximize individual subjective preference is introduced [Ando and Noson eds., Music and Concert Hall Acoustics, Academic Press, London, 1997]. It is remarkable that based on the model we can well describe primary sensations consisting of temporal sensations of sound signals and spatial sensations of sound fields [Ando, Sato and Sakai, in Sendra ed., Computational Acoustics in Architecture, WIT, Southampton, 1999; Ando, Journal of Sound and Vibration, 258, 405-417, 2002]. Thus, any subjective attributes of visual environments are being described in term of spatial and temporal factors extracted from correlation functions [Fujii, et al. Psychological Research, 64, 149-154, 2000; Soeta et al. NeuroReport, 13, 527-533, 2002].

For example, in order to develop personality of children, a temporal design may be made for their rooms with a workspace. And, to activate both cerebral hemispheres, and thus to find individual personality, work spaces at house and office may be designed. At the same time, an internet system between home and office is utilized realizing the minimum efforts (time and energy) and the maximum effects without attending everyday to a working place.

Keywords: temporal design (TD), TD for growth of body, mind and personality, creative work spaces (CWS) at house and office, design theory based on the temporal and spatial criteria, brain and subjective preference

1. INTRODUCTION

1.1. Three Stages of Time to be Designed

The rapid pace of change of our environment is making people wonder how long this environment will remain suitable for living. Up to the present, academic knowledge has been quite limited (Fig. 1), and has not been able to resolve this anxiety. To begin addressing this question from a temporal perspective, an attempt is made here of temporal design in architecture and the environment. This may be realized by addressing the relationship between man and the environment.

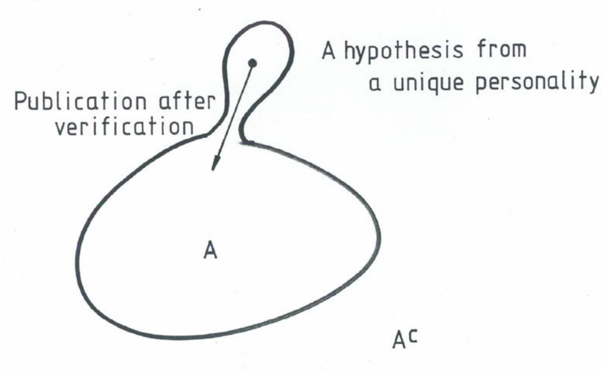


Fig. 1. Known limited A and infinite number of unknowns A^C.

a) Now at 3917-680 Takachiho, Makizono, Kagoshima, 899-6603 Japan, Professor Emeritus, Kobe University, andoy@cameo.plala.or.jp

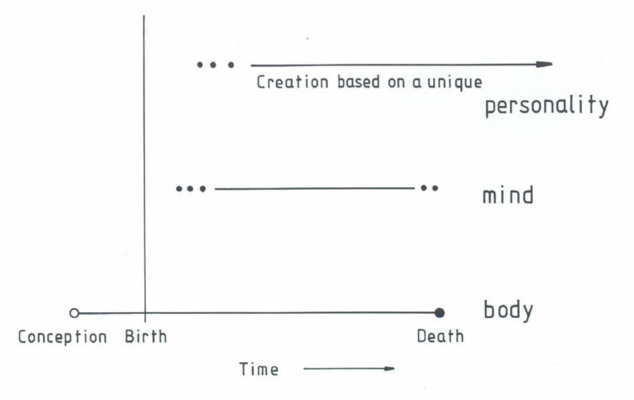


Fig. 2. Three stages of time to be considered for the temporal design.

It is also worth considering what could be thought of as three stages of human time (Fig. 2, Table 1):
(1) time of the body,
(2) time of the mind, and
(3) time of creation based on a unique personality.
The third life is the source of creation and the most unique to man. All healthy creations that may contribute to human life for a long time have been based on the unique and healthy personality of the individual. It is highly recommended, therefore, that the environment be designed for every stage of time, which is deeply related to each individual. A well-designed environment would be a meeting places for art and science, and in turn may help to discover the individual personality as the minimum unit of society.

It is worth noting that a lasting peace on earth maintaining the environment with time (life) in addition to space may be achieved by the release of each individual personality. Wars have been fought to release nations, races, religions and human-specified groups at the cost of human life and the environment. However, we have not fought to release the individual personality. From various fundamental academic activities, we do hope to synthesize meaningful environmental planning, which will take temporal values into consideration (Ando, 2001c). It is unlikely that “time is money,” but “time is life.”

First of all, a theory of designing physical environments that takes account of temporal factors together with spatial factors based on brain activities is described (Ando et al., 1996). A representative example of the application of this concept of environmental design may be found in concert hall acoustics (Ando, 1985, Sato et al., 1997, Ando, 1998) and Opera House Acoustics (Pompoli and Ando, 2000). The sound field

Table 1. Three stages of human life (time). Ill noise environment resulted and healthy environments to be designed, which are discussed in this paper.

Three stages of life (time)	Ill noise environment resulted	Healthy environment to be designed
III **Creation based on personality**		Examples of applications of CHA[1] for development of each individual personality: (5) Creative work station (CWS) (4) Seat selection maximize the individual preference (Kirishima International Music Hall; Internet Preference Testing System)
II **Mind**	(2) Time integrated effects of noise on brain development	(3) CHA based on auditory-brain model
I **Body**	(1) Time integrated effects of noise on unborn babies	

[1] Concert Hall Acoustics.

in a room can be altered with careful manipulation of four orthogonal factors describing subjective preference. These factors comprise two temporal factors, associated with the left hemisphere, and two spatial factors, associated with the right hemisphere. The spatial factors can determine the architectural form of the hall. The temporal factors are closely related to design of a specific concert hall, which can be altered to showcase specific types of music, such as organ music, chamber music or choral works. It is worth noticing that subjective preference is the most primitive response maintaining the life. And, personality as a source of creation may be related to subjective preference.

The purpose of this article is to apply a design concept in which both spatial and temporal factors are explicitly considered in a general theory of environmental planning and design. Applications of this theory in environmental design are demonstrated. To begin with, the model of auditory-brain system is discussed, which is concerned with the shortest temporal period represented by sound signals such as music and speech.

It is hoped that the survey presented here taking temporal factors in design of architecture and the environmental into account can suggest a suitable line for further investigations for existing man of about “six thousand million,” as of 2003.

1.2. Time Integrated Effects of Noise on Unborn Babies and Children

Since 1968, these investigations were performed around the Osaka International Airport, Japan.

(1) Body: Time integrated effects of the aircraft noise on developments of the body of unborn babies are briefly reviewed. It is worth noticing that there are many unconscious physiological rhythms than subjective psychological attributes associated with physical environmental activities of long periods. Effects of environmental noise are described in terms of human placental lactogen (HPL), thus in turn the development of unborn babies (Ando and Hattori, 1977a; Schell and Ando,1991).

(2) Mind: Time integrated effects on development of the cerebral hemispheres of children (mind, and in tern, personality) are described. Postnatal effects of aircraft noise on sleep of babies are depend on the period when their mother came into the noise area in reference to the period pregnancy (Ando and Hattori, 1973: Ando and Hattori, 1977b; Ando, 2001a). The body and brain developments of children over long period accumulations were clearly described by results of testing different mental works associated with the left and the right hemisphere (Nakane and Egawa, 1975; Ando, 1988; Ando 2001b).

2. MODEL OF AUDITORY-BRAIN SYSTEM

In order to discuss healthy sound environments the model of auditory-brain system is described here. This model is useful for measurements of environmental noise and to describe any of subjective responses of sound and sound field.

Based on the physical system and physiological responses, a model of the auditory-brain system may be formed for the independent acoustic factors, classified by comprehensive temporal and spatial factors (Ando, 1985, 1998). The model consists of the autocorrelation mechanisms, the interaural crosscorrelation mechanism between the two auditory pathways, and the specialization of human cerebral hemispheres for temporal and spatial factors of the sound field. In addition, according to the relationship of subjective preference the most primitive response and physiological phenomena in changes with variation to the acoustic factors, a model is shown in Fig. 3. In this figure, a sound source p(t) is located at r_0 in a three-dimensional space and a listener is sitting at r which is defined by the location of the center of the head, $h_{l,r}(r| r_0,t)$ being the impulse responses between r_0 and the left and right ear-canal entrances. The impulse responses of the external ear canal and the bone chain are $e_{l,r}(t)$ and $c_{l,r}(t)$, respectively. The velocities of the basilar membrane are expressed by $V_{l,r}(x, \varpi)$, x being the position along the membrane.

The action potentials from the hair cells are conducted and transmitted to the cochlear nuclei, the superior olivary complex including the medial superior olive, the lateral superior olive and the trapezoid body, and to two cerebral hemispheres. The input power density spectrum of the cochlea I(x') can be roughly mapped at a certain nerve position x' (Katsuki et al., 1958, Kiang, 1965), as a temporal activity. Such neural activities, in turn, include sufficient information to attain the autocorrelation function (ACF), at or near the lateral lemniscus as indicated by $\Phi_{ll}(\sigma)$ and $\Phi_{rr}(\sigma)$. In fact, the time domain analysis of firing rate from auditory nerve of cat reveals a pattern of ACF rather than the frequency domain analysis (Secker-Walker and Searle, 1990). Pooled interspike interval distributions resemble the short time or the running ACF for low-frequency component. And, pooled interval distributions for sound stimuli consisting of the high-frequency component resemble the envelope to running ACF (Cariani and Delgutte, 1996).

From a viewpoint of the missing fundamental or pitch of

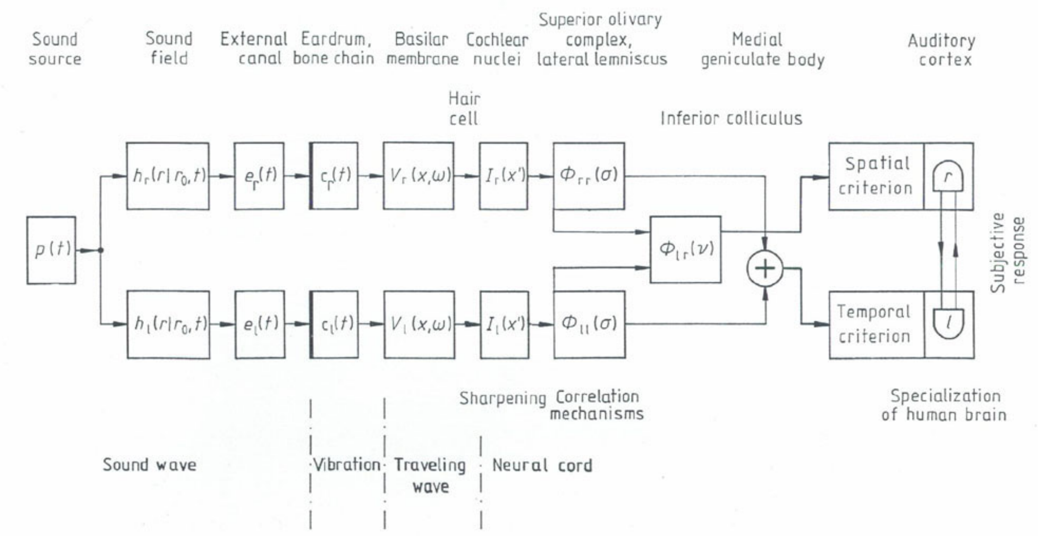


Fig. 3. Model of auditory-brain system (Ando, 1985).

complex components judged by human, the running ACF must be processed in the frequency components below about 5 kHz (Inoue et al., 2001). Due to the absolute refractory or resting period of a single neuron (about 1 ms), the missing fundamental or pitch, which corresponds to ϕ_1 of ACF of sound signal (Fig. 5), may be perceived less than about 1.2 kHz (Inoue et al., 2001). A model of running ACF processor existing after the peripheral frequency domain analysis is illustrated in Fig. 4, which may dominantly be connected with the left cerebral hemisphere.

As is also discussed (Ando, et al., 1991, Ando, 1998), the neural activity (wave V together with waves IV_l and IV_r) may correspond to the IACC. Thus, the interaural crosscorrelation mechanism may exist at the inferior colliculus. It is concluded that the output signal of the interaural crosscorrelation mechanism including the IACC (the magnitude of the interaural crosscorrelation function) may be dominantly connected to the right hemisphere. Also, the sound pressure level may be expressed by a geometrical average of ACFs for the two ears at the origin of time ($\sigma = 0$) and in fact appears in the latency at the inferior colliculus, may be processed in the right hemisphere (Ando, 1998).

The specialization of the human cerebral hemisphere may relate to the highly independent contribution between the spatial and temporal criteria on any subjective attributes. Based on the model, we can well describe primary and spatial sensations, thus any subjective attributes of sound fields in term of processes in the auditory pathways and the specialization of two cerebral hemisphereres (Ando, 2001a).

3. TEMPORAL AND SPATIAL FACTORS OF SOUND FIELDS

3.1. Factors Extracted from the ACF

The ACF and the power density spectrum mathematically contain the same information. There are three significant items, which can be extracted from the ACF:

(1) Energy represented at the origin of the delay, $\Phi_p(0)$, where $\Phi_p(\tau)$ is the ACF of p(t), p(t) being a source signal;

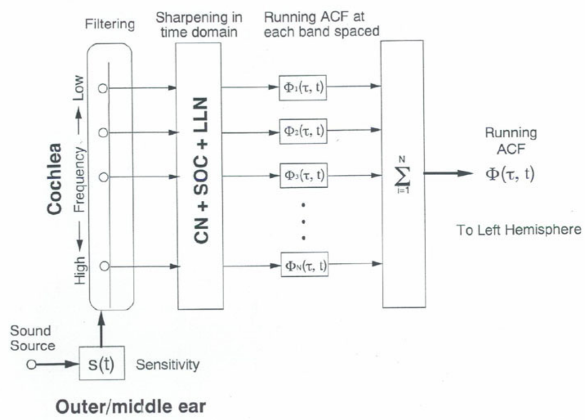
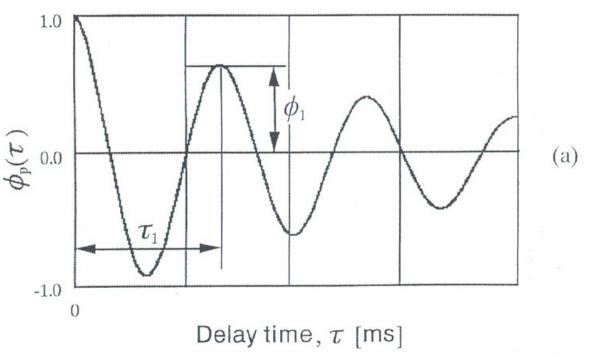


Fig. 4. Model of running ACF processor concerned in temporal factors of source signals and sound fields, which are deeply associated with the left hemisphere. S(t): the transfer function of physical system between a free field and the cochlea corresponding to the ear sensitivity (Ando, 1985, 1998). CN: Cochlear nuclei. SOC: Superior olivary complex. LLN: Lateral Lemniscus.



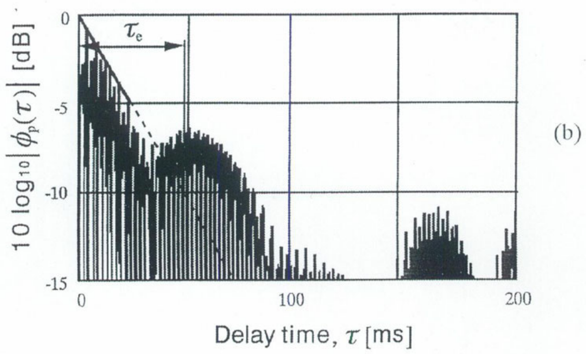


Fig. 5. Factors extracted from the ACF of source signals. (a) τ_1: delay time of the first peak corresponding to pitch or missing fundamental, which may not be obtained by the power spectrum of source signals. ϕ_1: Amplitude of the first peak corresponding to strength of the pitch. (b) τ_ε: Effective duration of ACF corresponding to a unit of delay time of preferred delay of initial reflection. The effective duration of ACF is defined by the delay τ at which the envelope of ACF becomes –10 dB (or 0.1; the ten percentile delay), can be easily obtained by the initial decay rate extrapolated in the range, for example, from 0 dB at the origin to –5 dB.

(2) Fine structure, including peaks and delays (Fig. 5a). Forinstance, τ_1 and ϕ_1 are the delay time and the amplitude of the first peak of ACF, τ_n and ϕ_n being the delay time and the amplitude of the n-th peak. Usually, there are certain correlation between τ_n and τ_{n+1}, and between ϕ_n and ϕ_{n+1};
(3) Effective duration of the envelope of the normalized ACF, τ_e, which is defined by the ten-percentile delay and which represents a repetitive feature or reverberation containing the sound source itself.

The normalized ACF is defined by

$$\phi_p(\tau) = \Phi_p(\tau) / \Phi_p(0) \qquad (1)$$

As a manner shown in Fig. 5b, this value is obtained by fitting a straight line on the initial decay envelope for obtaining extrapolation of delay time at –10 dB, if the initial envelope of ACF decays exponentially. Therefore, four temporal factors that can be extracted from the ACF are $\Phi_p(0)$, τ_1, ϕ_1, and the effective duration, τ_e.

3.2. Temporal Window

In analysis of the running ACF, the "auditory-temporal window," 2T obtaining $\Phi_p(\tau)$ in Equation (1), must be carefully determined. Since the initial part of ACF within the effective duration τ_e of the ACF contains important information of the signal, the recommended signal duration $(2T)_r$ to be analyzed is approximately given by

$$(2T)_r = 30(\tau_e)_{min} \qquad (2)$$

where $(\tau_e)_{min}$ is the minimum value of τ_e obtained by analyzing the running ACF (Mouri et al., 2001). Thus, the value of $(\tau_e)_{min}$ is considered as a unit of temporal window. And further, it is as a unit of delay time of preferred initial reflection and preferred reverberation time as expressed by Equations (8) and (9), respectively. The running step is selected as $Rs = K_2(2T)_r$, K_2 being, say, in the range of 1/4 - 1/2.

3.3. Factors Extracted From the InterAural Crosscorrelation Function (IACF)

Spatial factors extracted from the IACF, IACC, τ_{IACC}, and W_{IACC} are defined in Fig. 6 (Ando, 1998). The listening level, LL, is given by

$$LL = 10\log[\Phi_{ll}(0)\Phi_{rr}(0)] \qquad (3)$$

where $\Phi_{ll}(0)\Phi_{rr}(0)$ are sound energies of the signal arriving at the left and right ear entrances.

Remarkably, the temporal factors and the special factors, respectively, describe primary sensations and special sensations (Ando, 2001b).

3.4. Temporal and Spatial Factors of Sound Field

The results of the paired acoustic comparison tests with a number of subjects indicated that acoustic quality in a concert hall and an opera house can be fully described using the following four orthogonal factors:

Temporal factors of Sound Fields, which relate to the purpose of an enclosure:

1) The initial time delay gap between the direct sound and the first reflection (Δt_1);

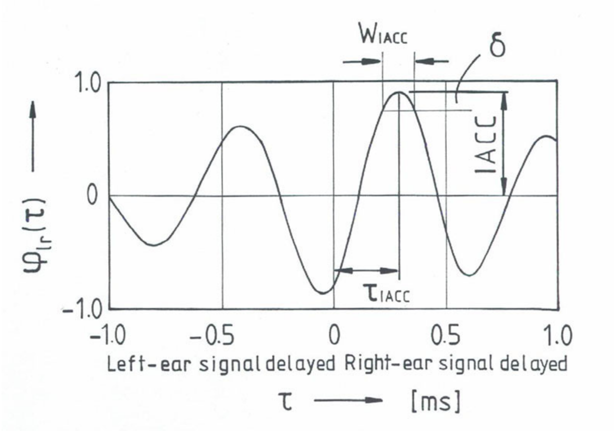


Fig. 6. Spatial factors extracted from the IACF. IACC: maximum amplitude of the IACF. τ_{IACC}: interaural delay at the maximum. W_{IACC}: width at τ_{IACC}.

2) Subsequent reverberation time of the signal after the early reflections (T_{sub});

Spatial factors relating to the architectural form of an enclosure:

3) Listening level of the sound (LL);

4) The magnitude of interaural cross-correlation (IACC) - the similarity in sound signals arriving at the two ears.

The first two factors are the "temporal-monaural" criteria are associated with the left hemisphere. They describe the sound field at a point in space, as it would be perceived by only one ear. The preferred conditions of temporal factors depend mainly upon the repetitive feature of source signals which can be classified by the effective duration of its ACF (Fig. 5). The third and fourth are "spatial-binaural" criteria dominantly associated with the right hemisphere. They have a spatial dimension, because the two ears perceive spatial sensations. These four orthogonal factors are taken into account in architectural design of the interior of a concert hall.

3.5. An Example of Individual Brain Responses Correspond to Subjective Preference in Relation to the Temporal Factor

Subjective preference is the most primitive response of any living organism, so that the direction of such a response is to maintain the life. To investigate human cortical responses that correspond to subjective preference of sound fields, an attempt has been made to analyze ACF of magnetoencephalography (MEG) under the condition of varying the delay time of single reflections (Soeta et al., 2002a). According to previous studies (Ando, 1998), it is assumed that a similar repetitive feature of the MEG alpha-waves range (8-13 Hz) is related to subjective preference in terms of the effective duration of the ACF. The source signal was a word "piano", which had a 0.35-s duration. The value of $(\tau_e)_{min}$ is approximately 20 ms. The delay time of the single reflection, Δt_1, was varied at five levels. The scale values of the subjective preference of each subject were obtained by the paired-comparison tests. To compare the results of the MEG measurements with the scale values of the subjective preference, combinations of a reference stimulus (Δt_1 = 0 ms) and test stimuli (Δt_1 = 0, 5, 20, 60, and 100 ms) were presented alternately 50 times, and the MEGs were analyzed.

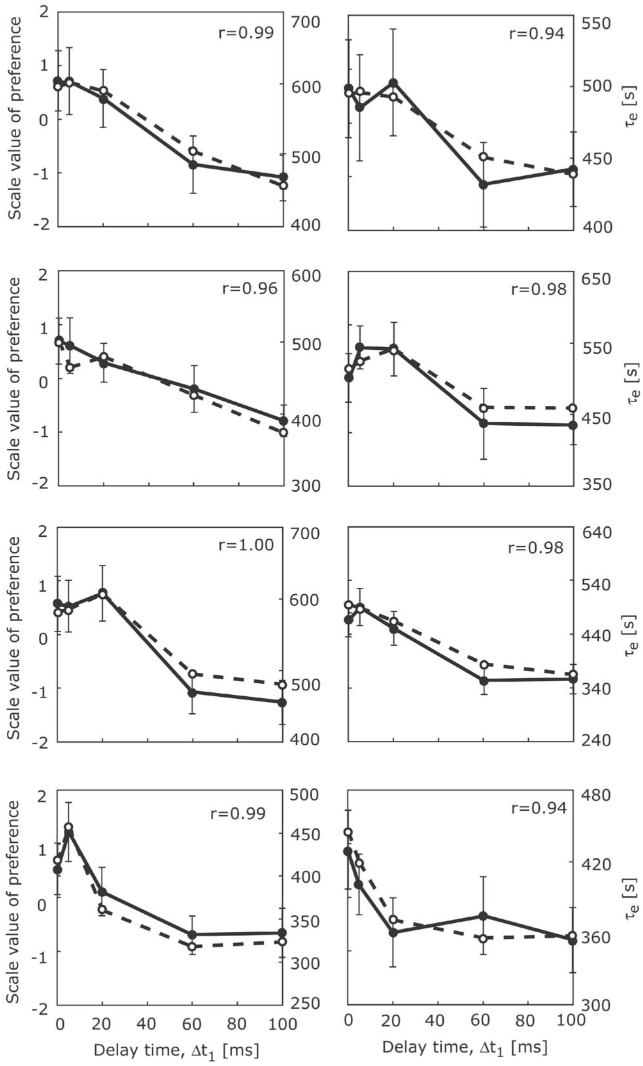


Fig. 7. Individual relationship between scale values of subjective preference and the effective duration of ACF of the MEG alpha wave $(\tau_e)_{MEG\alpha}$ (Examples of eight different subjects). The source signal was speech with the effective duration of ACF, $(\tau_e)_{min}$ is about 20 ms. Thus, the calculated most preferred delay time for global subjects is 20 ms according to Equation (8), A = 1.0 (Ando, 1985). Dotted lines indicate the scale value of subjective preference of each individual obtained by the paired-comparison test, and solid lines are averaged values of $(\tau_e)_{MEG\alpha}$ with the 95% confidence interval.

The remarkable finding are demonstrated in Fig. 7. Subjective preference for each individual and the effective duration of the ACF of the MEG alpha waves of the individual are linearly related. The correlation coefficient between them was +0.94 in the left hemisphere and +0.90 in the right one. The energy of the alpha wave measured by $\Phi(0)$ of its ACF in the left hemisphere was significantly greater than that in the right one. This reconfirms the left hemisphere dominance in the change of Δt_1. It is worth noticing that a preferred condition may induce the repetitive alpha waves in a wide brain area (Soeta et al., 2002b).

3.6. Theory of Acoustic Design

If physical environments other than the sound field are fixed, then each orthogonal factor may express the scale value of subjective preference obtained by the principle of comparative judgments. The principle of superposition holds only in the range of the preferred conditions tested by the judgments useful for design. Since it has been found that there are highly independent influences between the temporal and spatial factors on subjective preference judgments, the total scale value of the preference may be described by the superposition such that

$$S = [S_2 + S_3]_{Left} + [S_1 + S_4]_{Right} \qquad (4)$$

where

$$S \approx \alpha|x_i|^{3/2} \quad i, = 1, 2, 3, 4 \qquad (5)$$

The weighting coefficients α_i of each orthogonal factor have been obtained by a series of paired-comparison tests for subjective preference of simulated sound fields as listed in Table 2 (Ando, 1985, 1998).

Normalized factors namely X_2 and X_3, respectively, are expressed by

$$X_2 = \log (\Delta t_1 / [\Delta t_1]_p) \qquad (6)$$

$$X_3 = \log (T_{sub} / [T_{sub}]_p) \qquad (7)$$

where

$$[\Delta t_1]_p \approx (1 - \log_{10}A)\, (\tau_e)_{min} \qquad (8)$$

$$[T_{sub}]_p \approx 23\, (\tau_e)_{min} \qquad (9)$$

The symbol A signifies the total pressure amplitude of both reflections and reverberation. The minimum value represents the most active piece of source signals, which strongly affects subjective judgments. The four orthogonal factors, LL, IACC, and Δt_1 can be calculated at each seat by the use of an architectural plan. The reverberation time T_{sub} can be obtained by well known Sabine′s formulas at the design stage, such that

$$T_{sub} = kV/\alpha S \qquad (10)$$

Where k is constant (0.162), V is the volume of the room [m^3], α is the averaged value of absorption coefficient of the wall surface S [m^2].

The factor X_1 is given by the sound pressure level difference, measured by the A-weighted network, so that

$$X_1 = LL - [LL]_p \qquad (11)$$

where $[LL]_p$ indicates the most preferred listening level that can be assumed at a particular seat position in the room under design. Another typical and the right-hemisphere-related spatial factor is the magnitude of the IACF, i.e.,

$$X_4 = IACC \qquad (12)$$

So far, the scale values of preference have been formulated by Equation (5) approximately in terms of the 3/2 power of the normalized objective parameters, expressed in the logarithm of factors, X_1, X_2 and X_3. On the other hand, the spatial-binaural factor X_4 is expressed in terms of the 3/2 power of its real value of IACC, indicating a greater contribution than temporal factors. It is worth noticing that there are minor individual differences in subjective preference as a function of IACC.

Table 2. Four orthogonal factors of sound fields and its weighting coefficients α_i obtained with a number of subjects.

		α_i	
i	x_i	$x_i>0$	$x_i<0$
1	$20\log P - 20\log[P]_p$ [dB]	0.07	0.04
2	$\log(\Delta t_1/[\Delta t_1]_p)$	1.42	1.11
3	$\log(T_{sub}/[T_{sub}]_p)$	0.45 + 0.75A	2.36 - 0.42A
4	IACC	1.45	---

However, large individual differences are found only in the temporal factors as well as LL. Equation (5) signifies that the scale values are not greatly changed in the neighborhood of the most preferred conditions ($X_i = 0, i = 1, 2, 3, 4$), but decrease rapidly outside of this range. This design theory is reconfirmed by subjective preference tests at a number of seats changing source location on the stage in a concert hall (Sato et al., 1997).

4. DESIGN STUDIES OF CONCERT HALLS

4.1. Design Studies of Sound Fields for Concert Halls as a Public Space

Using the optimal values in the four objective factors of sound fields obtained by a number of listeners, the "principle of superposition" expressed by Equation (4) can be applied to determine the scale value of preference at each seat. Comparison of the total preference values for different configurations of a concert hall allows a designer to choose the best for a range of specific music programs.

Let us now discuss the quality of the sound field in a concert hall with a shape similar to that of Symphony Hall in Boston. Suppose that a single source is located at the center, 1.2 m above the stage floor. Receiving points in the hall at a height of 1.1 meters above the floor level correspond to the ear positions. Reflections with their amplitudes, delay times, and directions of arrival at the listeners are taken into account using the image method. Contour lines of the total scale value of preference for the present shape of the symphony hall calculated for Music B (Sinfornetta by Arnold: see Ando, 1985, 1998) are shown in Fig. 8(a). Adjusting sidewalls on the stage may produce decreasing values of IACC for the audience area. Therefore, as shown in Fig. 8(b), the preference value at each seat is increased in comparison with that in Fig. 8(a). That figure demonstrates importance of the side reflections from the stage. In this calculation, the reverberation time is assumed to be 1.8 seconds throughout the hall and the most preferred listening level, $[LL]_p$ in Equation (11), is set for a point on the center line 20 meters from the source position.

If a conductor or music director is aware of the acoustic characteristics of a concert hall, one is able to plan a program of music that will sound best in that hall. It has been found, for example, that music with rapid movements sounds best in a concert hall with a short Δt_1, and a short T_{sub}. Music with a slow tempo sounds usually best in a hall with relatively long values for the factor Δt_1 and T_{sub}. This is classified by the minimum value of effective duration of ACF of source signals. An ideal application of this principle would allow the architect, concert hall manager, and music director to collaborate and actually change the configuration of a given concert hall to suit a specific music program. A "sound coordinator" could tune the concert hall for a program of music, just as the instruments in the orchestra are tuned at the beginning of a concert.

Better concert halls could be designed using a process that maximizes scale values of preference. Since a small value of IACC (a typical spatial factor), which corresponds to different sound signals arriving at two ears, is preferred for each individual without exception. Not due to symmetry of cerebral hemisphere, a symmetrical shape of concert hall is recommended as well.

Applications of this design theory were performed in the Kirishima International Concert Hall, designed by the architect Fumihiko Maki as shown in Fig. 9 (Maki, 1997, Nakajima and Ando, 1997). Another example is Tsuyama Music Cultural Hall (Suzumura et al., 2000), that has 52 columns (30-cm diameters) as a design element in the hall (Photo 1). The columns provide surfaces for scattering reflected sound waves for the higher frequency range above 1 kHz, at the seating-center area near to the stage. This brings about a small value of IACC. In addition, the height of triangular reflectors installed above the stage may be adjusted, according to the effective duration τ_e of the ACF for music in a program. This canopy plays an important role in decreasing the IACC at the seating area close to the stage also. The acoustic environment inside

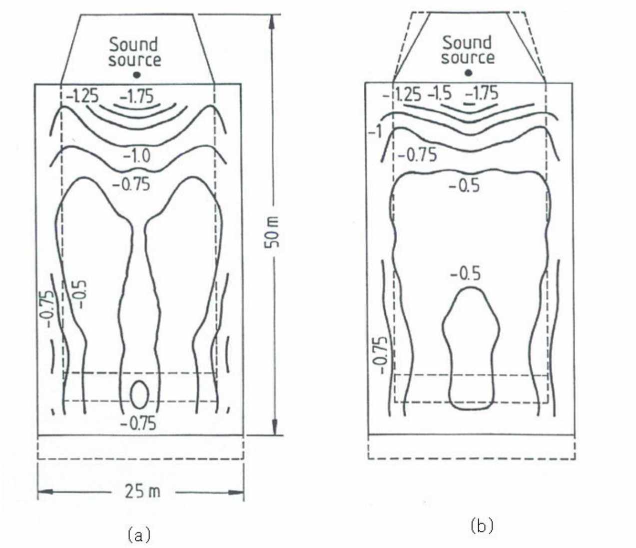


Fig. 8. The total scale values of subjective preference calculated by Equation (4) with the four orthogonal factors of sound fields. (a) Contour lines of the scale value for Boston Symphony Hall with original side reflectors on the stage, and (b) those with side reflectors optimized.

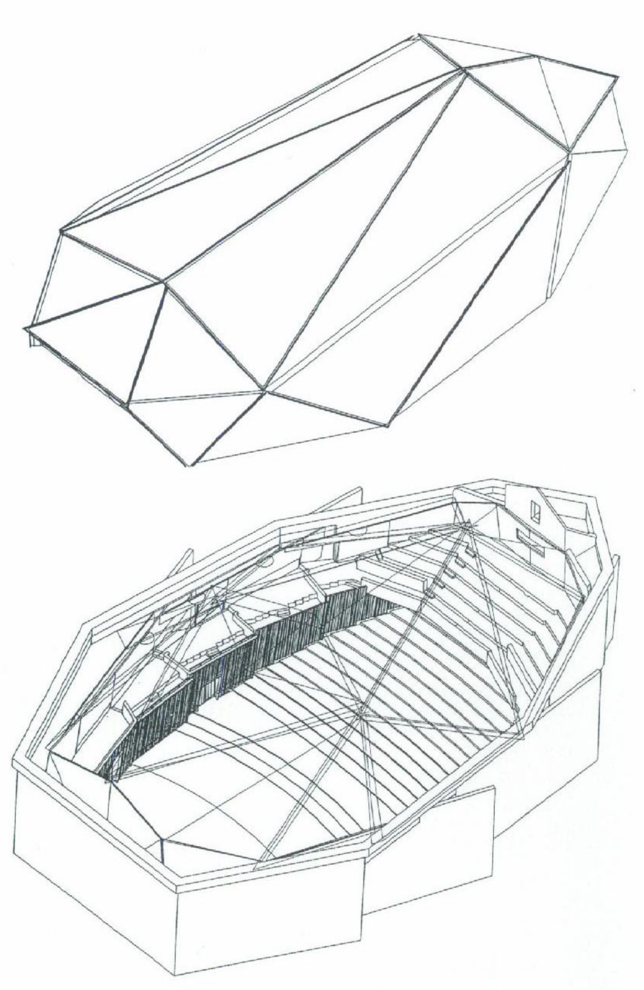


Fig. 9. The final scheme of the Kirishima International Concert Hall.

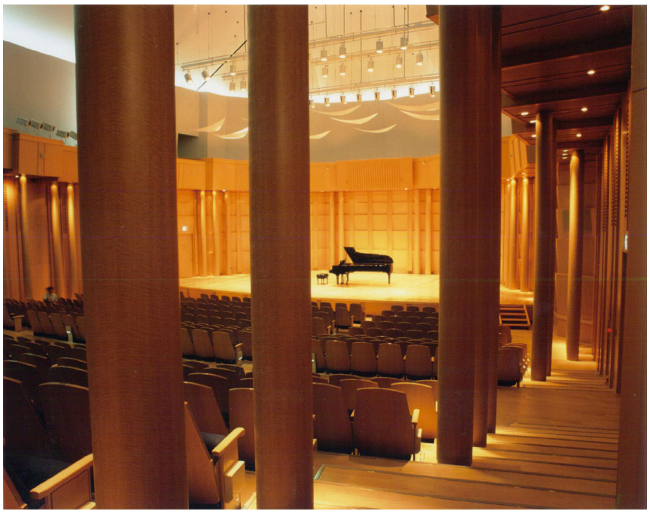


Photo 1. The Tsuyama Music Cultural Hall with 52 columns around the wall and reflectors above the stage.

these halls will be well suited to chamber music, with a $(\tau_e)_{min}$ in the range of 50 - 90 ms, because the reverberation time is about 1.7 s with audience.

4.2. Seat Selection for Each Individual in a Public Hall

So far, we have discussed "global subjective preference tests," which analyze responses of a number of subjects. In order to maximize the individual subjective preference for each listener, a seat selection system testing his or her own preference has been introduced (Sakurai et al., 1997). This kind of test may be realized by use of a simulation system changing each of four factors. An example of each of four factors tested for a single listener is demonstrated in Fig. 10, and resulting preferred seat

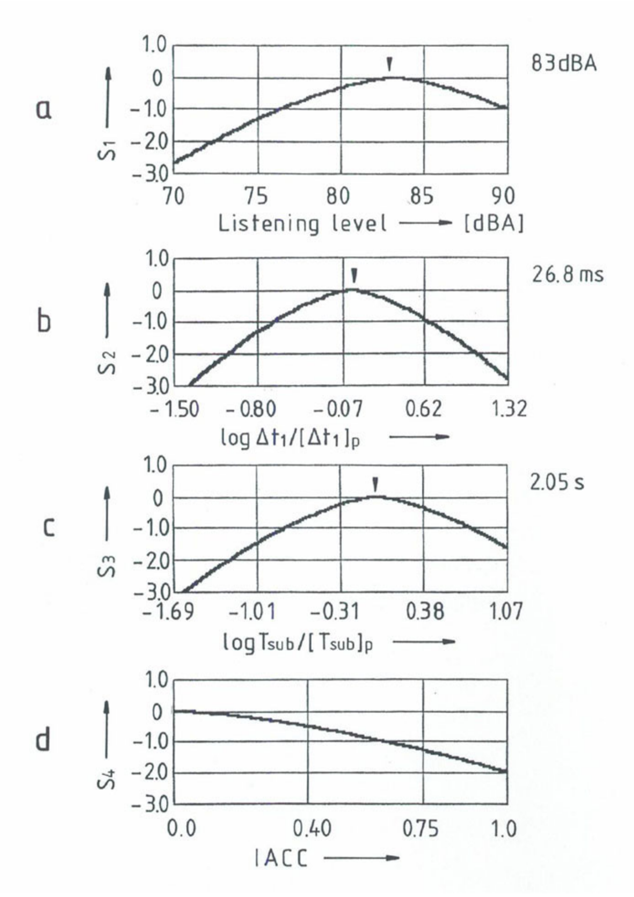


Fig. 10. Scale values of preference obtained by tests for the four factors, subject BL. (a) The most preferred listening level was 83 dBA, the individual weighting coefficient in Equation (5): $\alpha_1 = 0.06$; (b) $[\Delta t_1]_p$ was 26.8 ms, the individual weighting coefficient in Equation (5): $\alpha_2 = 1.86$, where $[\Delta t_1]_p$ calculated by Equation (8) with $(\tau_e)_{min} = 62$ ms for the music used (A = 4) was 24.8 ms; (c) $[T_{sub}]_p$ is 2.05 s, the individual weighting coefficient in Equation (9.10): $\alpha_3 = 1.46$, where $[T_{sub}]_p$, calculated by Equation (9) with $\tau_e = 62$ ms for the music used, is 1.43 s; (d) Individual weighting coefficient in Equation (5): $\alpha_4 = 1.96$.

area are shown in Fig. 11.

Since individual preferences do not change much in relation to the IACC (Ando, 1998), preferences for the other three factors are much more important to finding an individual's preferred seat in a given concert hall. Figure 12 shows three-dimensional illustration of preferred three factors for 106 listeners who participated at the international symposium, MCHA 1995. A method testing "individual preferences," that would allow creation of an Internet auralization system will be appeared in due course (http://www.ymec.co.jp/eg.htm). Since a concert hall plays important role for growth of the left and right cerebral hemispheres, this kind of system is highly recommended to find a personal characteristics for each of children. The preference theory may be applied for evaluating environmental noise as well (Ando and Heiss, 2001). An application for vision will be discussed below.

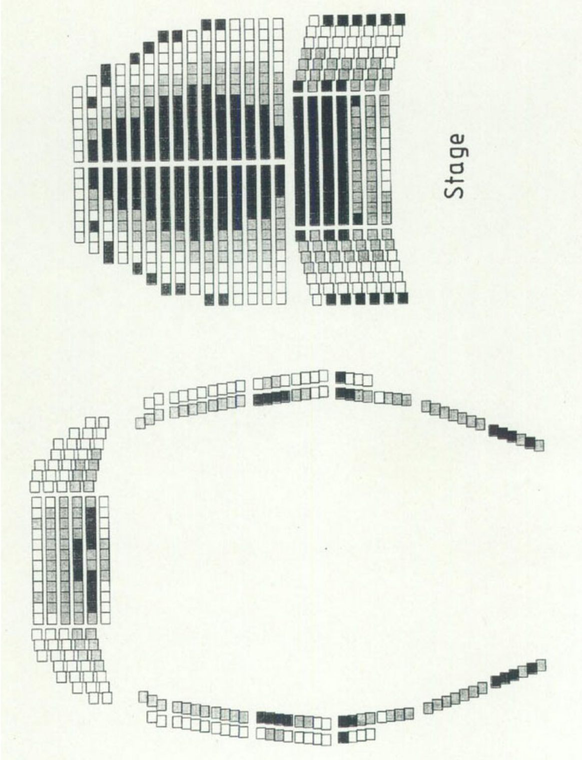


Fig. 11. Preferred seat area calculated for subject BL. The seats are classified in three parts according to the scale values of preference calculated by the summation S1 through S4. Black seats indicate preferred areas, about one third of all seats in this concert hall, for subject BL.

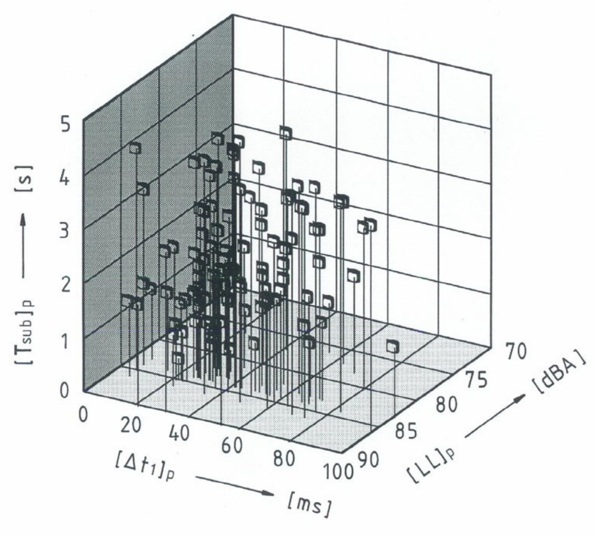


Fig. 12. Three-dimensional illustration of preferred three factors of sound field for 106 subjects who participated at the international symposium of MCHA'95 (Ando and Noson, 1977). Preferred conditions are distributed in a certain range of each factor so that subjects could not be classified into any "*specific groups*".

5. SOME APPLICATIONS FOR BASIC RESEARCH IN VISION

5.1 Missing Fundamental Phenomenon as a Visual Temporal Sensation

Similar to the missing fundamental of the complex components or the pitch sensation in acoustics, it was found that observed perceived a flicker rate in vision at the fundamental frequency, although any energy at this frequency was not included in the complex signals (Fujii et al., 2000). This phenomenon is true even in the random-phase conditions of complex signals, in which the period of the fundamental component is unclear in the real waveforms. One possible mechanism for extracting such a periodicity in the complex signal is the ACF to the real temporal waveforms.

5.2 Subjective Preference in Relation to Temporal Factor of a Flickering Light

Human cortical responses corresponding to the subjective preference for a flickering light of varying period were investigated (Soeta et al., 2002c). Paired-comparison tests were performed to examine the subjective preference for a flickering light, and magnetoencephalography (MEG) were recorded during presentations of the most preferred and less preferred flickering lights alternately. Results showed that the effective duration of the ACF, τ_e, which represents a repetitive feature of the MEG alpha waves, becomes longer during the preferred condition. This reconfirms that the brain repeats a similar rhythm under preferred conditions in vision as well.

6. TEMPORAL DESIGNS IN ARCHITECTURE AND IN THE ENVIRONMENTS

In our life, as shown in Fig. 13, experiences of discrete periods of human and physical environments may be blended. Remarkably, there are certain significant periodic "eigen" values in both human biological rhythms and physical environmental activities in the time domain to be designed.

Following musical tempo (Fig. 13), there are eigen values: About 90 minutes corresponding to rapid eye movement (REM) or period during sleep and wakefulness in man, one day, one week, one month, one year or four seasons, about 30 years as a generation change, about 90 years as a human life time and so on. Thus, we do not need to consider every "real" time period, since there is a potential of an infinity of scales. Thus, a crucial factor in the temporal dimension of the environment is cycles. Every aspect of the passage of time is bound up with cycles: birth and death, the changing of the seasons, sleeping and waking, work and leisure. The present theory suggests that these cycles should be explicitly recognized during the design process. The passage of time in the designed environment should be as consciously considered as the three-dimensional organization of the space itself.

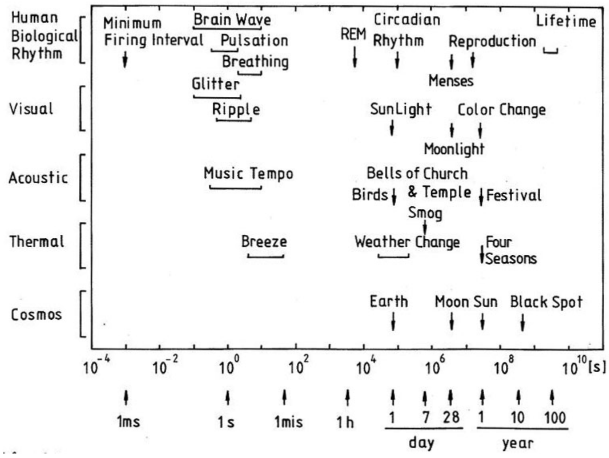


Fig. 13. Blending human biological rhythms and discrete periods of natural physical environments.

6.1 Creative Work Space in an Office and a Residence

For the third stage of time discussed in Introduction, an attempt is being made for an office system and a space for working at home for the company or institution. The temporal period of work must be about 90 - 120 min., which corresponds to sleep and wakefulness period (Othmer et al., 1969). An example of the system is shown in Fig 14. Eight systems of this type have been introduced in March 2002 to Ando Lab., Kobe University (Photo 2). It consists of three different directional panels for the left and right hemispheric tasks (Ando 1988, 2001a), and for an information-communication system. Thus, it is hoped that multiple dimensional ideas may be much more easily created. This quite differs from a usual ″one-dimensional″ working space. Eight users were reported that the total qualities of this system were 2.5 - 15 times (average 7 times) better than the usual desks, which they used previously, and efficiencies of works increased to 2 - 15 times (average 5 times). All of users, therefore, reported efficiencies were more than 2 times at least ($p < 0.01$).

6.2 Play Area and Education in Term of Time for Children

We now discuss design of the environment for a play area as a "stage" of development of body, mind and creation for children (Fig. 2). Wood structures, flexible bridges, and fanciful designs allow for much freer play of imagination and creation than the hard surfaces. It is also easy to see why natural areas such as small streams are so fascinating to children. The stream is an "interactive toy," changing course and speed as the child performs small scale engineering projects. This interaction holds the child's interest, because it has a time factor: the "toy" itself changes due to the child's actions, and indeed continues changing even after the child stands back to admire his or her work. Thus, environments well designed in term of time may play important role for development of children.

It is worth noticing that the similar considerations should

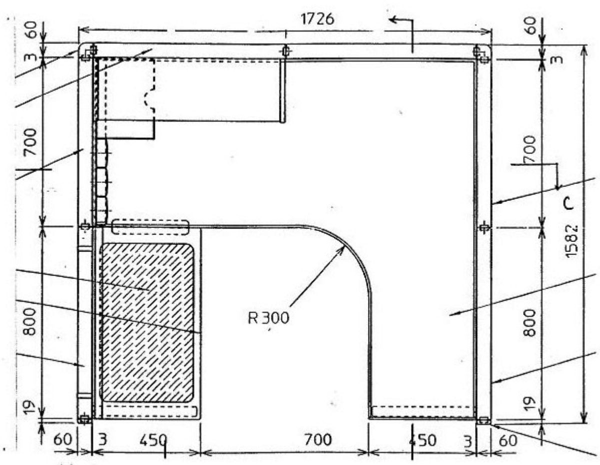


Fig. 14. "Creative Work Space (CWS)" introduced at Ando Lab., Kobe University. Shaded part of desk panel on the left-hand side is used for works of space related works such as painting, drawings and handicraft; front panel and right panel are used for the information system and works with temporal processing such as writing, calculating and logical works.

(a)

(b)

(c)

Photo 2. Views of CWS and a large table for discussion and coffee break located near to the CWS. (a) Inside of CWS displaying by results of investigation for preparation of a manuscript of paper. A top panel of the left hand side is made of cork and a user may use cutter knife, and even hammer activating the right hemisphere. (b) A top panel is used for writing and reading with the left hemisphere, and a white board on the panel is used for discussion and memory. (c) A large table for discussion and coffee break located near to the CWS with a member of Ando's Laboratory.

be paid for education in term of the time. For example, there are certain "temporal windows" in the brain in development learning different languages. As far as duration experience is concerned, a tendency was found that subjective time duration during the senior high school are much shorter than that during the elemental school (Ando et al., 1999). In other words, the subjective duration of children is decreased with aging. The degree of brain development resulting from new experiences and new information from environment. When children transfer to other elementary school at 6 to 11 years of age, the subjective duration was much longer than those who did not move.

7. REMARKS

It is considered by results of systematical investigations on the effects of environmental noise that any environmental stress suffering to pregnant mothers may be absorbed by the unusual additional organism of placenta, and thus affects on the development of unborn babies. Such a stress may further affect on the development of individual personality as a source of creation contributing to any of living creatures.

It is strongly hoped, therefore, that the method developed here may allow one to design the human delightful environment by basing temporal factors on a limited number of environmental variables. The optimum range of values for each of these variables for a given environment, and the independence of each, can be determined by paired comparison tests, as used in the study of acoustics. These variables comprise two temporal factors of the left hemisphere dominance, and two factors of the right hemisphere dominance that are related to spatial attributes. The overall subjective preference may be described as a total from these variables. More reliable data for determining preferred values for a range of subjects are being obtained using what might be termed the effective duration of ACF of the alpha waves of EEG and MEG. Also, based on the model of auditory-brain system, temporal sensations of source signals and spatial sensations of sound fields may be described (Ando, 2001a).

Once the variables and their level of interdependence are determined, a matrix of these variables and relationships would allow a designer to analyze a range of proposed designs, and determine which is suited to each individual and then number of people for a given design program. The matrix would be distinguished by its conscious incorporation of the temporal dimension of human experience.

The most typical time of human activity is utilized for a creation based on the unique personality. It is hoped that the survey presented here taking temporal factors in design of architecture and the environment into account can suggest a suitable line for further investigations to maintain healthy and creative environments for man (see Journal of Temporal Design in Architecture and the Environment: http://www.jtdweb.org/

journal/). Particularly, a set of knowledge “A” shown in Fig 1 in designing the long-time environment for the time more than about 30 years is premature.

*This paper was presented as the lecture of ″Laurea Honoris Causa″ at the Aula Magna, University of Ferrara on 12 June 2002, it was jointed with the Meeting of Acoustical Association of Italy.

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