Preface

This book is one of the first scientific attempts to relate aesthetics to neural activity patterns in both auditory and visual areas of the brain. We present a host of correspondences between human subjective preferences and brain activity as observed through electroencephalography (EEG) and magnetoencephalography (MEG).

The multimodal set of investigations presented in this book grew out of the development of a neurally grounded theory of subjective preference for sound fields in concert halls. The theory is based on a model of the human auditory system (Ando, 1985, 1998, 2007). In the theory, subjective preference is shaped by ecological utility to embody patterns of primitive responses that enhance survival. The auditory preference model assumes two kinds of internal representations of sound that are based on the correlation structure of sound as it presents itself to the two ears. These representations are based on autocorrelation and crosscorrelation. The autocorrelation function (ACF) describes the monaural signal at each of the two ears, and the interaural crosscorrelation function (IACF) describes the correlations between the two monaural signals arriving at the entrances of the two ears.

The autocorrelation and crosscorrelation representations have a firm neural basis in the temporal patterning of spike activity in the early stages of auditory processing. These time domain neural representations complement more familiar frequency domain representations that are based on spatial patterns of elevated neural discharge. At the level of the auditory nerve, the spatial, spectral representations embody Helmholtz's cochlear "place principle," while temporal patterns of spike discharge at each cochlear place faithfully follow the time structure of the filtered acoustic waveform. Temporal patterns of spikes can then be analyzed by higher auditory stations to extract information about the acoustic source and its spatial surrounds. Being temporal correlation representations rather than spatial profiles of neuronal excitation, they have a form and neural implementation that is much different from those associated with the power spectrum. In addition to temporal representations of the acoustic form of the stimulus, we have also found correlates of subjective preferences in temporal response properties at several points in the auditory pathway.

Part I of this book discusses central autocorrelation (ACF) and binaural crosscorrelation (IACF) representations that we believe respectively subserve perception of tonal quality and of auditory spatial attributes. Many aspects of tonal quality, including pitch, timbre, loudness, and duration, can be extracted from features of the central autocorrelation representation. On the other hand, spatial sensations such as localization in the horizontal plane, apparent source width (ASW), and subjective diffuseness may be described in terms of spatial factors extracted from the central crosscorrelation representation (IACF). Table 1 gives an overview of the perceptual attributes, their internal representations, likely locations, and neurophysiological observables.

Thus, the various attributes of the "primary sensation" of the whole sound can be divided into two categories: "temporal sensations" and "spatial sensations." Any subjective responses of the sound field, therefore, may be described in terms of combinations of temporal and spatial factors. Further, these two sets of factors appear to be processed somewhat differently in the two cerebral hemispheres. The temporal factors extracted from the ACF appear to be associated with neuronal responses from the left cerebral hemisphere, whereas the spatial factors extracted from the IACF appear to be associated with those of the right hemisphere. Such hemispheric specialization and the relative independence of the two types of representation may play important roles in shaping the structure of subjective judgments.

Part II of this book discusses similarities between auditory and visual processing. Although the theory of subjective preference was developed with auditory perception in mind, it can plausibly be extended to predict subjective preferences in analogous dimensions of visual perception. Analogies can then be drawn to temporal and spatial sensations of vision, as well as for subjective preferences of visual environments. For example, the most preferred condition of a flickering light is expressed by the temporal factors extracted from the autocorrelation (ACF) of the temporally modulated light stimulus. The preference curve in relation to one of the temporal factors is given by a common formula such that

$$S \approx -\alpha\,|x|^{\beta}$$

where S is relative preference, α is a scaling coefficient that depends on the particular individual, and x is the factor normalized by his or her most preferred value. Remarkably, the form of the curve is invariant across subjects, with β always having a fixed value of 3/2.

This relation also holds true for the subjective preference curve in relation to each of four orthogonal factors for the sound field; that is,

1. listening level (LL),
2. initial delay time between the direct sound and the first reflection (Δt_1),
3. subsequent reverberation time (T_{sub}), and
4. the IACC, which is the maximum magnitude of the IACF.

However, few acousticians or musicians know the value of their own, most-preferred reverberation time, and our tests have shown great individual differences of subjective preference in relation to such temporal factors and listening levels. On the other hand, most subjects prefer sound sources that are spatially more diffuse

Table 1 Summary of temporal and spatial sensations as well as subjective preference in relation to factors extracted from the ACF and IACF together with four orthogonal factors of the sound field and the physiological locus and observables to be described in Part I of this volume

Quality or attribute	Acoustic correlate	Representation	Main factor	Locus	Observable(s)	Section(s)
Temporal sensations and preference						
Periodicity pitch	Fundamental frequency	ACF	τ_1 and ϕ_1 extracted from ACF	brainstem (Left hemisphere)	Single units, ABR	5.1, 6.2
Loudness	Source signal	ACF	τ_1, τ_e in the condition of constant LL	brainstem (Left hemisphere)	ABR	4.1, 4.2, 5.1, 6.4
Duration sensation	Duration	ACF	Signal duration D and τ_1 extracted from ACF	brainstem (Left hemisphere)	ABR	4.1, 6.5
Timbre	Power spectrum	ACF	$W_{\phi(0)}$ extracted from ACF	Left hemisphere	Single unit	5.1
Preferred first reflection, $[\Delta t_1]_p$	Distance of nearest reflecting surface	ACF	τ_e extracted from ACF	Left hemisphere	SVR, EEG, MEG	3.1, 4.3, 4.4
Preferred reverberation time, $[T_{sub}]_p$	Volume of a room and absorption	ACF	τ_e extracted from ACF	Left hemisphere	EEG	3.2, 4.3
Spatial sensations and preference						
Localization (azimuth)	Source position	IACF	τ_{IACC} and IACC extracted from IACF	brainstem Right hemisphere	ABR	4.1, 7.1
ASW	Location of reflectors and frequency component	IACF	IACC, W_{IACC}, LL	brainstem Right hemisphere	ABR, SVR	4.1, 4.2, 7.2
Subjective diffuseness	Location of reflectors	IACF	IACC, LL	brainstem Right hemisphere	ABR, SVR	4.1, 4.2, 7.3
Preferred listening level, $[LL]_p$	Distance from the source to receiving position, volume of a room and absorption	IACF	LL	brainstem Right hemisphere	ABR, SVR	3.2, 4.1, 4.2
Preferred IACC: a small value	Location of reflectors	IACF	IACC	brainstem Right hemisphere	ABR, SVR	3.2, 4.1, 4.2

and enveloping, i.e. they produce low IACC values with correspondingly high subjective diffuseness. Because subjects may differ as to which aspects of sounds they care about most, we have developed a model of individual preference that adjusts the relative weights of the associated spatial and temporal factors.

It is remarkable that neural activities include sufficient information to reconstruct the ACF of the stimulus. For example, at the level of the auditory nerve, Cariani and Delgutte (1996) found that pooled interspike interval distributions resemble the short time, or running ACF for lower-frequency components that are perceptually resolved. For sets of stimulus components with higher harmonic numbers that cannot be perceptually resolved, the pooled interval distributions that are produced reflect time-locking to waveform envelopes such that their form therefore resembles the envelope of the running ACF.

At the cortical level, a feature of the autocorrelation of alpha waves of both EEG and MEG corresponded to subjective preference of the reverberatory characteristics of sound fields. The repetitive feature of the EEG alpha wave, the "effective duration" of its ACF, was always observed at the preferred condition. This means that the basic theory of subjective preference can be applied to each individual's preferences for this parameter. We reconfirmed by the alpha wave of MEG that the left cerebral hemisphere response is associated with preferred first reflection time Δt_1 and found that the effective duration of the ACF of the MEG alpha wave directly corresponds to the magnitude of an individual's subjective preference. The right cerebral hemisphere was activated by the typical spatial factors, that is, the magnitude of interaural crosscorrelation (IACC), which reflects the spatial subjective diffuseness of the sound field.

This book largely serves as a record of the research performed at the Ando Laboratory, Graduate School of Science and Technology, Kobe University, between 1969 and 2009, even after the author's retirement. The first part of this volume recapitulates previous experiments whose results were reported by the author in 1985 and 1998. To describe clearly the important facts that were discovered, details of each investigation are recounted to avoid confusion. In the interest of space, we have left several issues out of this volume that were discussed in the 1998 book. Among them are the descriptions of the physical system from the free field to the oval window, which accounts for the sensitivity of the ear, and the details of our method for obtaining individual preference profiles.

It is hoped that this volume will make a useful and lasting contribution to research that relates acoustics and the brain, from the architectural acoustics of concert halls and opera houses, to the effects of noise on humans, to the psychological and physiologic acoustics of speech and music perception.

The minimum unit of society is the individual, and an individual's subjective preference may be a reflection of a unique personality or perspective. The individual personality generates creative ideas, which persist long after the individual has passed on. If the life of the body is the "first life," and that of the mind is the second, then the propagation of one's ideas constitutes yet another, "third life." A healthy creation can contribute to human society and the environment in this third life for a long time even after the end of the first and second ones. Ideas can create better environments for thinking. A self-conscious design process that incorporates spatial and temporal factors can facilitate more productive interactions between brains and environments that in turn induces still further discoveries and creations. In this way, the design of human thinking environments amplifies itself in an open-ended, creative way that persists long after the human beings who initiated it have left the scene (Fig. 1).

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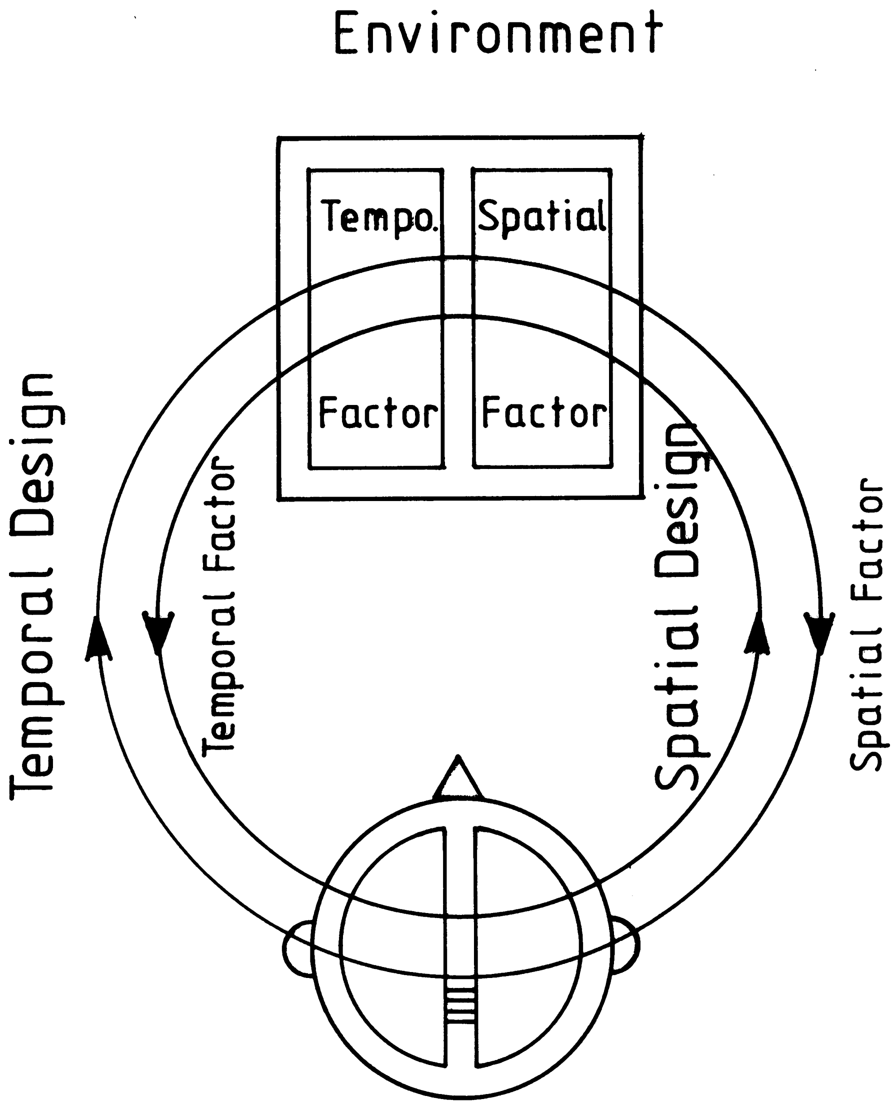

Fig. 1 Interaction between brain and environment created by incorporating with temporal and spatial factors, which are associated with the left and right cerebral hemispheres, respectively. Such an environment realized by each individual may induce further discoveries and creations (Ando, 2009)

Previous Publications Related to This Topic

Ando, Y. (1985). Concert Hall Acoustics. Springer-Verlag, Heidelberg.
Ando, Y. (1998). Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners. AIP Press/Springer-Verlag, New York.
Ando, Y. (2007). Concert hall acoustics based on subjective preference theory. In: Rossing, T. (ed.), Handbook of Acoustics. Springer-Verlag, New York, Chapter 10.
Ando, Y. (2009). Theory of temporal and spatial design of environment. In: Blumel, D. (ed.), McGraw-Hill 2009 Yearbook of Science and Technology. McGraw-Hill, New York.

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